TECHNICAL EVALUATION REPORT

OPERATING REACTOR PORV REPORTS (F-37)

TMI ACTION PLAN REQUIREMENTS

WESTINGHOUSE OWNERS GROUP, WCAP-9804

NRC DOCKET NO. Various.

NRC CONTRACT NO. NRC-03-81-130

FRC PROJECT C5506

FRC ASSIGNMENT 7

FRC TASK 408

Prepared by

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Prepared for

Nuclear Regulatory Commission
Washington, D.C. 20555

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February 15, 1983

Revised April 21, 1983

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FOREWORD

This Technical Evaluation Report was prepared by Franklin Research Center under a contract with the U.S. Nuclear Regulatory Commission (Office of Nuclear Reactor Regulation, Division of Operating Reactors) for technical assistance in support of NRC operating reactor licensing actions. The technical evaluation was conducted in accordance with criteria established by the NRC.

Mr. G. J. Overbeck, Mr. T. J. DelGaizo, and Mr. S. M. Jenkins contributed to the technical preparation of this report through a subcontract with WESTEC Services, Inc.

1. INTRODUCTION

1.1 PURPOSE OF REVIEW

This technical evaluation report (TER) documents an independent review of a Westinghouse Owners Group (WOG) Report prepared in response to NUREG-0737 [1], "Clarification of TMI Action Plan Requirements," Item II.K.3.2, "Report on Overall Safety Effect of Power Operated Relief Valve Isolation System." This evaluation was performed with the following objectives:

- o to assure that the WOG Report is complete and properly documents the information required by NUREG-0737, Item II.K.3.2
- o to assure that the estimated probabilities of the WOG Report satisfy the review criteria.

1.2 GENERIC BACKGROUND

In NUREG-0611 [2], "Generic Evaluation of Feedwater Transients and Small Break Loss-of-Coolant Accidents in Westinghouse-Designed Operating Plants," the Nuclear Regulatory Commission's (NRC) Bulletins and Orders Task Force recommended the following:

- o "All pressurized water reactor (PWR) licensees should provide a system which uses the block valve to protect against a small break loss-of-coolant accident (LOCA). This system will cause the block valve to close automatically when the reactor coolant system (RCS) pressure decays after the power operated relief valve (PORV) has opened to relieve excess pressure. An override feature should be incorporated. Justification should be provided to assure that failure of this system would not decrease overall safety by intensifying plant transients and accidents.
- o Westinghouse should prepare a report documenting the various actions which have been taken to decrease the probability of a small break LOCA caused by a stuck-open PORV and show how these actions constitute sufficient improvements in reactor safety.
- o Safety valve failure rates based on past history of the Westinghouse-designed plants should be included in the report specified above."

These recommendations were later included in NUREG-0660 [3], "NRC Action Plan Developed as a Result of the TMI-2 Accident." The first recommendation

was incorporated into NUREG-0660 as Item II.K.3.1, "Installation and Testing of Automatic Power-Operated Relief Valve Isolation System," and the second two recommendations were combined to form Item II.K.3.2, "Report on Overall Safety Effect of Power-Operated Relief Valve Isolation System." In Reference 1, the staff delayed implementation of Item II.K.3.1, until the pending PORV reliability analysis of Item II.K.3.2 confirmed the necessity of an automatic isolation system. Specifically, NUREG-0737, Item II.K.3.2 stated:

"(1) The licensee should submit a report for staff review documenting the various actions taken to decrease the probability of a small-break loss-of-coolant accident (LOCA) caused by a stuck-open power-operated relief valve (PORV) and show how those actions constitute sufficient improvements in reactor safety.

(2) Safety-valve failure rates based on past history of the operating plant designed by the specific nuclear steam supply system (NSSS) vendor should be included in the report submitted in response to (1) above."

In addition, Reference 1 further clarified that:

"Modifications to reduce the likelihood of a stuck-open PORV will be considered sufficient improvements in reactor safety if they reduce the probability of a small-break LOCA caused by a stuck-open PORV such that it is not a significant contributor to the probability of a small-break LOCA due to all causes. (According to WASH-1400, the median probability of a small-break LOCA S_2 with a break diameter between 0.5 in. and 2.0 in. is 10^{-3} per reactor-year with a variation ranging from 10^{-2} to 10^{-4} per reactor-year.)

The above-specified report should also include an analysis of safety-valve failures based on the operating experience of the pressurized-water-reactor (PWR) vendor designs. The licensee has the option of preparing and submitting either a plant-specific or a generic report. If a generic report is submitted, each licensee should document the applicability of the generic report to his own plant.

Based on the above guidance and clarification, each licensee should perform an analysis of the probability of a small-break LOCA caused by a stuck-open PORV or safety valve. This analysis should consider modifications which have been made since the TMI-2 accident to improve the probability. This analysis shall evaluate the effect of an automatic PORV isolation system specified in Task Action Plan Item II.K.3.1. In evaluating the automatic PORV isolation system, the potential of causing a subsequent stuck-open safety valve and the overall effect on safety (e.g., effect on other accidents) should be examined.

Actual operational data may be used in this analysis where appropriate. The bases for any assumptions used should be clearly stated and justified.

The results of the probability analysis should then be used to determine whether the modifications already implemented have reduced the probability of a small-break LOCA due to a stuck-open PORV or safety valve a sufficient amount to satisfy the criterion stated above, or whether the automatic PORV isolation system specified in Task Action Item II.K.3.1 is necessary.

In addition to the analysis described above, the licensee should compile operational data regarding pressurizer safety valves for PWR vendor designs. These data should then be used to determine safety-valve failure rates.

The analysis should be documented in a report. If this requirement is implemented on a generic basis, each licensee should review the appropriate generic report and document its applicability to his own plant(s). The report and the documentation of applicability (where appropriate) should be submitted for NRC staff review by the specified date."

1.3 PLANT-SPECIFIC BACKGROUND

In response to NUREG-0737, Items II.K.3.1 and II.K.3.2, in 1981, licensees of Westinghouse-designed plants endorsed and submitted to the NRC [4], the WOG Report (WCAP-9804); "Probabilistic Analysis and Operational Data in Response to NUREG-0737, Item II.K.3.2 for Westinghouse Plants" [5]. A preliminary review of the report resulted in the NRC's sending a request for additional information (RAI) to one of the licensees on February 11, 1982 [6]. The Licensee responded to the RAI in a letter to the NRC dated March 26, 1982 [7]. This TER evaluates the information in Reference 5, as supplemented by Reference 7, along with other information pertinent to the topic of small-break LOCA from a stuck-open PORV or safety valve.

2. REVIEW CRITERIA

The Westinghouse Owners Group response to NUREG-0737, Item II.K.3.2, was evaluated against the acceptance criteria provided by the NRC in a letter dated July 21, 1981 [8], which outlined Tentative Work Assignment F. Specifically, the response to NUREG-0737, Item II.K.3.2 was supposed to contain the following information:

"1. The report shall list the actions taken by the licensee to decrease the probability of a small-break LOCA caused by a stuck-open PORV.

2. The report shall include an analysis of safety-valve failure rate based on the past history of the operating plants designed by the licensee's NSSS vendor. This may be a plant-specific report or a generic report showing the applicability to the specific plant.

3. The report shall have an analysis of the probability of a small-break LOCA caused by a stuck-open PORV or a stuck-open safety valve. This analysis shall evaluate the effect of an automatic PORV isolation system. In evaluating this system, the licensee shall evaluate the potential of causing a subsequent stuck-open safety valve and the overall effect on safety.

4. Actual operational data may be used. The basis for any assumption should be clearly stated and justified.

5. The automatic PORV isolation system is not required if the licensee's actions constitute sufficient improvements to reactor safety in reducing the probability of a small-break LOCA due to a stuck-open PORV or a stuck-open safety valve such that it is less than 10^{-3}/reactor year, the median probability of a small-break LOCA S_2 with a break size between 0.5 in. and 2.0 in. due to all causes."

On July 26, 1982 [9] and September 17, 1982 [10], the NRC clarified that the probability of a small-break LOCA due to a stuck-open PORV or safety valve did not necessarily have to be less than 10^{-3} per reactor-year. Instead, a comparison of pre-TMI and post-TMI data should demonstrate that plant modifications have reduced the probability of a small-break LOCA due to a stuck-open PORV or safety valve and that this reduction should be sufficient to approach the WASH-1400 median probability of a small-break LOCA S_2 with a break diameter between 0.5 and 2.0 in.

3. TECHNICAL EVALUATION

The following tasks were to be performed under contract to the NRC [8]:

1. Review the licensee's report required by NUREG-0737, Item II.K.3.2 to determine (1) if a licensee proposes to provide an automatic PORV isolation system and (2) if all the data required in the report have been provided by the licensee. Review the licensee's analysis for completeness in identifying all transients that lead to PORV challenges. The analysis should include failure in the integrated control system (ICS), applicable to Babcock & Wilcox (B&W) plants only, operator error, reliability of PORV block valve, and other initiating events. Review the licensee's analysis of safety valve challenge rate and failure rate to reseat. The analysis should include consideration of the PORV being blocked as a result of leakage, operator action closing the PORV block valve and actuating high pressure injection (HPI) during the recovery from depressurization events.

2. Evaluate the licensee's reports required by NUREG-0737, Item II.K.3.2 against the review criteria in Section 2. If generic reports are submitted, the applicability of the generic reports to the specific plants, should be evaluated. Priority should be given to determining if any of the PWR licensees is required to propose an automatic PORV isolation system. If necessary, a letter was to be provided requesting these PWR licensees to propose such systems and the plant-specific technical basis for this request.

3. Prepare a TER for each plant. The TER will discuss the evaluation of the licensee's reports and, if needed, the proposed automatic PORV isolation system. The TER shall include a discussion of the assumptions made by the licensee in his reports.

This report constitutes a TER in satisfaction of Task 3. Section 3.1 addresses the completeness of the WOG Report, while Section 3.2 provides an evaluation of the analyses.

3.1 REVIEW OF THE WOG REPORT FOR COMPLETENESS

The review and evaluation of the information presented in Reference 5, as supplemented by the additional information presented in Reference 7, forms the basis of this report. Reference 5 was prepared for the Westinghouse Owners Group by the Westinghouse Electric Corporation for the purpose of generically addressing the requirements of NUREG-0737, Item II.K.3.2. (See Section 1.2 of

this report for more detailed information pertaining to the requirements of NUREG-0737, Item II.K.3.2.) In Reference 5, Westinghouse describes the various modifications that have been incorporated into Westinghouse-designed plants since the Three Mile Island (TMI) accident and presents a probabilistic analysis of the likelihood of a small-break LOCA from a stuck-open PORV or safety valve. Included in the probabilistic analysis is the evaluation of a pre-TMI Westinghouse-designed baseline plant, the effect on the plant of the post-TMI modifications as implemented, and the effect of a conceptually designed automatic PORV isolation system as identified in NUREG-0737, Item II.K.3.1.

3.1.1 Technical Approach

Several methodologies presently exist for determining the frequency of a small-break LOCA caused by a stuck-open PORV or safety valve. Inherent in all of these methodologies is the requirement to determine the frequency and number of PORV or safety valve challenges (demands to open) and the probability of the PORV or safety valve failing to close once it has opened. The probabilistic analysis tool that Westinghouse chose to use in Reference 5 is the event tree. As demonstrated in WASH-1400 [9], "Reactor Safety Study, An Assessment of Accident Risks in U.S. Commercial Nuclear Power Plants," the use of the event tree as a probablistic analysis tool is an acceptable technical approach for analyzing reactor incidents such as a stuck-open PORV or safety valve.

Since Westinghouse has used a well documented probablistic analysis technique, a detailed evaluation of the technical approach is not required. The following subsections which describe Westinghouse's analysis as presented in References 5 and 7 are provided for clarity.

3.1.1.1 Event Tree Transient Initiators

Westinghouse selected 16 transients as the initiating events for their PORV small-break LOCA evaluation. The transients selected, their pre-TMI frequency, and the reference source of the event frequency are shown in Table 1. As indicated on Table 1, Westinghouse used data from EPRI NP-801 [11], "ATWS: A

Table 1. Event Tree Transient Initiators

Transient Number	Transient Name	Pre-TMI Frequency (number per reactor-year)	Source of Event Frequency
T1	Loss of main feedwater, offsite power available	3.0	See Note 1
T2	Loss of main feedwater due to and coincident with loss of offsite ac power	0.27	EPRI NP-801, Transient Category 35, Loss of Station Power
T3	Loss of main feedwater coincident with loss of all ac power	7.0×10^{-6}	See Note 2
T4	Turbine trip (direct reactor trip)	1.0	EPRI NP-801, Transient Category 33, Turbine Trip, Throttle Valve Closure, EHC Problems
T5	Large load rejection without turbine trip	1.0	See Note 2
T6	MSIV closure (all loops)	0.07	EPRI NP-801, Transient Category 18, Closure of All MSIV
T7A	Inadvertent safety injection, high-head plants (see Note 3)	0.01	EPRI NP-801, Transient Category 9, Inadvertent Safety Injection Signal
T7B	Inadvertent safety injection, low head plants (see Note 3)	0.01	EPRI NP-801, Transient Category 9, Inadvertent Safety Injection Signal
T8	Main feedline rupture	1.0×10^{-4}	See Note 2

Table 1 (Cont.)

Transient Number	Transient Name	Pre-TMI Frequency (number per reactor-year)	Source of Event Frequency
T9A	Main steamline rupture, high-head plants (see Note 3)	1.0×10^{-4}	See Note 2
T9B	Main steamline rupture, low-head plants (see Note 3)	1.0×10^{-4}	See Note 2
T10	Chemical volume control system (CCVS) malfunction resulting in power increase	0.03	EPRI NP-801, Transient Category 11, CVCS Malfunction-Boron Dilution
T11	Partial loss of reactor coolant flow (1 loop)	0.12	EPRI NP-801, Transient Category 1, Loss of RCS Flow (1 Loop)
T12	Complete loss of reactor coolant flow (excluded loss of offsite power)	0.01	EPRI NP-801, Transient Category 14, Total Loss of RCS Flow
T13	Locked (or sheared) reactor coolant pump rotor	1.0×10^{-3}	See Note 2
T14	Uncontrolled bank withdrawal resulting in power increase	0.01	EPRI NP-801, Transient Category 2, Uncontrolled Rod Withdrawal
T15	Inadvertent PORV opening	0.02	EPRI NP-801, Transient Category 8, Pressurizer Relief or Safety Valve Opening
T16	Excessive steam generator tube leakage or tube rupture	0.03	EPRI NP-801, Transient Category 26, Steam Generator Leakage

Table 1 (Cont.)

Notes:

1. The frequency noted is a summation of the frequencies assigned in EPRI NP-801 [11] to transient categories 15, Loss or Reduction in Feedwater Flow (1 Loop); 16, Total Loss of Feedwater Flow (All Loops); 21, Feedwater Flow Instability - Operator Error; 22, Feedwater Flow Instability - Miscellaneous Mechanical Causes; 23, Loss of Condensate Pumps (1 Loop); 24, Loss of Condensate Pumps (All Loops); 26, Steam Generator Leakage; 27, Condenser Leakage; 28, Miscellaneous Leakage in Secondary System; and 29, Sudden Opening of Steam Relief Valves.

2. The frequency was estimated using conservative engineering judgment, WASH-1400, and other ongoing studies.

3. High-head plants are those with safety injection pumps capable of producing sufficient pressure to challenge open the PORVs and safety valves. Low-head plants are the others.

Reappraisal, Part III, Frequency of Anticipated Transients" to estimate the recurring frequency of the higher probability transient initiators. For those transient initiators with a lower frequency of occurrence not included in Reference 11, conservative engineering judgments were made as to the frequency using various sources, such as Reference 9, as the basis for estimating occurrences such as pipe ruptures. In addition, of the 41 PWR transient categories defined in Reference 11, only those transients which have the potential of causing the PORV or safety valve to open were chosen as initiating events. Furthermore, transients such as a rod control assembly ejection accident, which by virture of their nature are already classified as small-break LOCAs, have been excluded, regardless of whether or not the PORV or safety valve would be challenged to open.

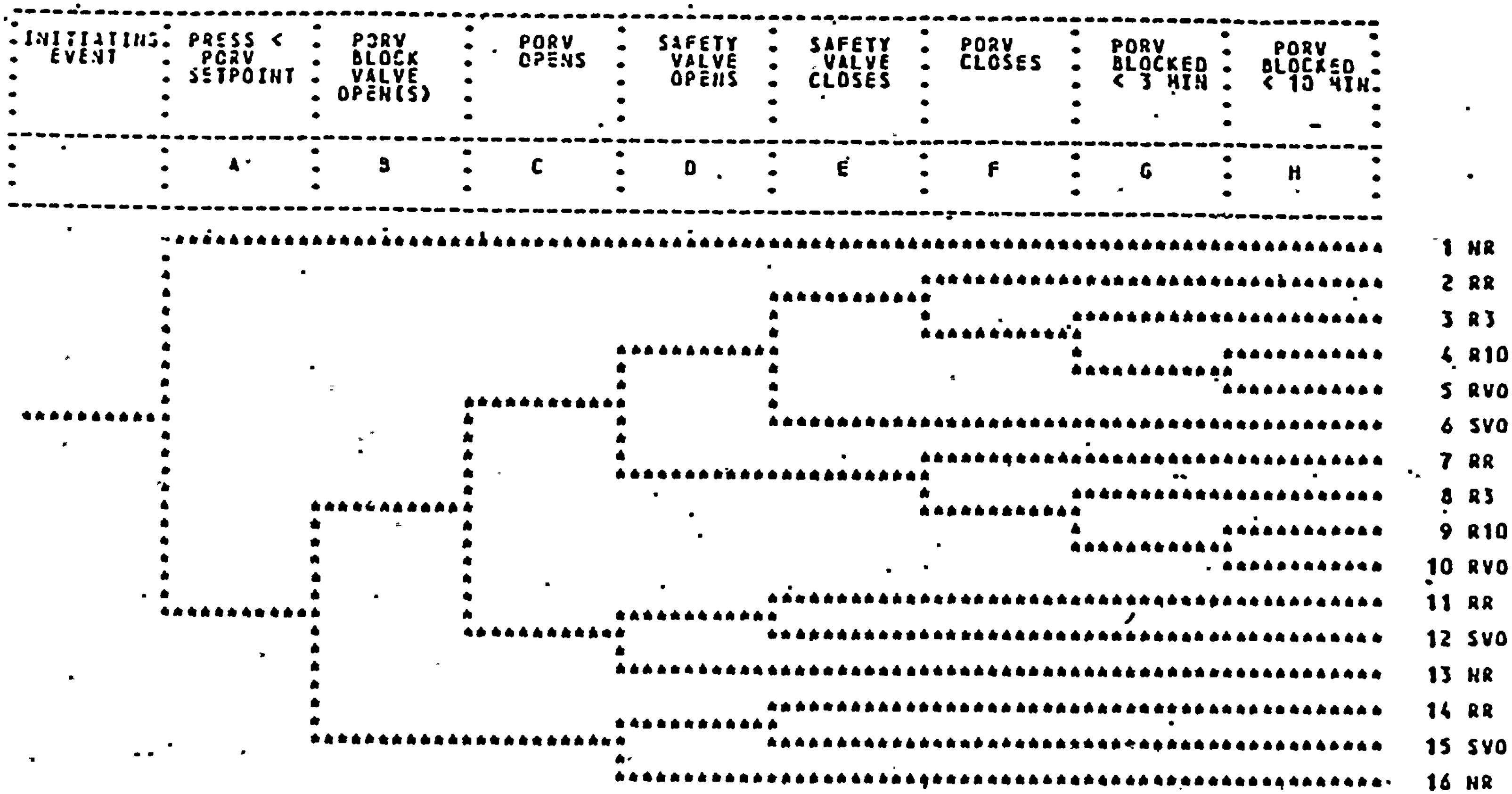
3.1.1.2 Event Tree Branches and End Points

In Reference 5, Westinghouse developed two event trees which were used with the transient initiators identified in Section 3.1.1.1 of this report to evaluate the probability of a small-break LOCA from a stuck-open PORV or safety valve. One event tree (Figure 3.2 of Reference 5) was used for all of the transient initiators except for the transient initiator T15, inadvertent PORV opening. Inadvertent PORV opening was evaluated using a more simplified event tree (Figure 3.3 of Reference 5). Figures 3.2 and 3.3 of Reference 5 are included here for informational purposes as Figures 1 and 2, respectively.

The branch nodes, as defined by Westinghouse in Reference 5, for the event tree used for transient initiators T1 through T14 and T16 are given as follows:

"NODE A

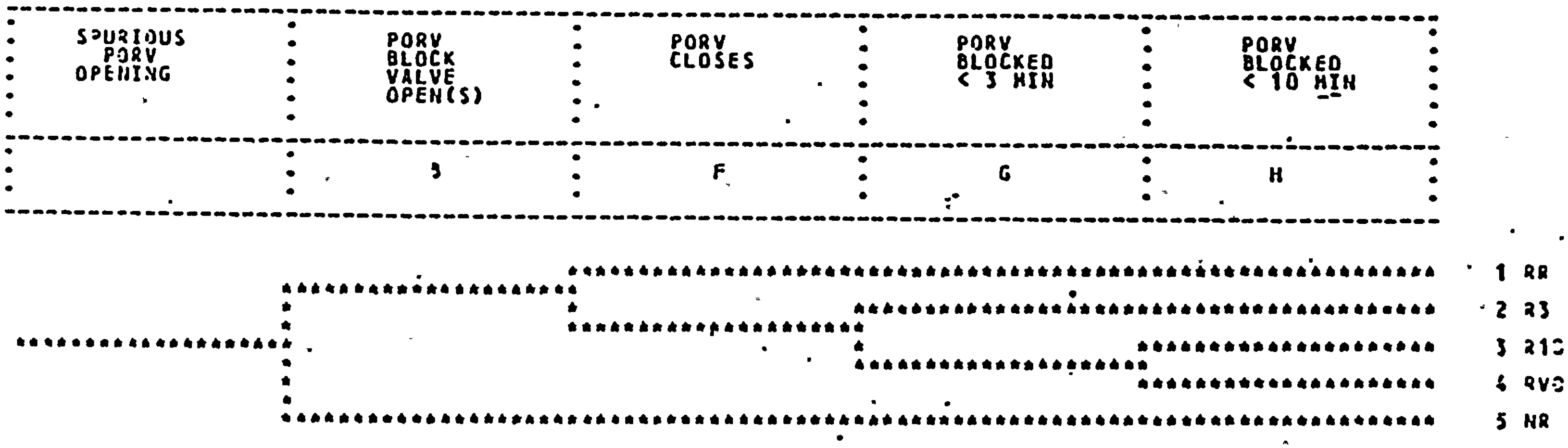
PEPORV Setpoint — Upward paths at this node indicate that a demand was not made on the PORV due to a pressure increase above the PORV opening setpoint. The recommended setpoint for the PORV opening is 2350 psia on Westinghouse plants. Downward paths at this node indicate that the pressure was sufficiently high to cause the PORV to open. The probability at this node represents the various means of causing the PORV set pressure to be reached given the initiator.



CATEGORY DESCRIPTION

NR	NO RELIEF
RR	RELIEF+RECLOSE
R3	RELIEF,FAIL OPEN,CLOSE IN 3 MIN
R10	RELIEF,FAIL OPEN,CLOSE IN 10 MIN
RVO	RELIEF VALVE FAILS OPEN
SVO	SAFETY VALVE FAILS OPEN

Figure 1. Transient Event Tree for Transients T1 Through T14



: CATEGORY DESCRIPTION

NR	NO RELIEF
RR	RELIEF+RECLOSE
R3	RELIEF,FAIL OPEN,CLOSE IN 3 MIN
R10	RELIEF,FAIL OPEN,CLOSE IN 10 MIN
RVO	RELIEF VALVE FAILS OPEN

Figure 2. Transient Event Tree for Spurious PORV Opening

NODE B

Block Valve open (s)

Upward paths represent those where at least one PORV block valve is open when the challenge to the PORV occurs. This applies both to the cases where the PORV block valve is manually positioned, and the case of automatic open/closure systems where the block valve may be automatically moved. Downward paths represent those where all PORV block valves are closed when the PORV setpoint is reached. This node is not considered to be relevant for paths where the PORV set pressure is not exceeded, as represented by the trees which have a P<2350 event. (Spurious PORV opening is considered in a separate tree.) Intentional PORV blocking due to valve leakage is incorporated into the probability for success/failure at this node. For a system (manual) where all PORVs are blocked 55 percent of the time, the branches would be assigned .45/.55 for success/failure respectively.

NODE C

PORV opens

Upward paths represent PORV opening. Downward paths represent PORV staying closed. Since this question is only asked for paths which show P>2350 and block valves open, the probability of the PORV staying closed represents the failure to open on demand. This probability for the PORV must therefore include such failure sources as pressure channels, solenoids, solenoid valves, as well as those associated directly with the valve. The spurious PORV opening during each transient is not included in the event trees but is considered as an initiating event in a separate event tree for inadvertent PORV opening.

NODE D

Safety valves opens

Upward paths represent the opening of a safety valve. Downward paths represent the safety valve staying closed. The actual significance of this question is whether the safety valve set pressure is exceeded; i.e., the failure of a safety valve to open at pressures above its set pressure is not considered. The set pressure for safety valves is the RCS design pressure and is 2500 psia for Westinghouse plants. For those special cases where both the safety and relief valves are expected to open, the probability of the safety valve opening must reflect this. [Note: In Reference 5, Westinghouse uses the notation P(D: B and C) and P(D: B or C). P(D: B and C) refers to the case in which the block valve is open (P(B)) and the PORV opens (P(C)). P(D: B or C) refers to the case in which either the block valve is closed or in which the block valve is open but the PORV does not open.]

NODE E

Safety valve recloses	Upward paths represent the successful reclosing of a pressurizer safety valve when the pressurizer pressure falls below the set pressure. Downward paths represent the failure of a safety valve to reclose when the pressurizer pressure falls below the set pressure.

NODE F

PORV recloses	Upward paths represent the successful reclosing of a pressurizer PORV when the pressurizer pressure falls below the PORV closure set pressure. Downward paths represent the failure of a PORV to reclose subsequent to an opening. This question is only considered for paths which result in relief through the PORV.

NODE G

Block valves recloses <3* minutes after PORV closure demand	Upward paths represent PORV isolation less than three minutes after the PORV is supposed to have closed. Downward paths represent failure of the PORV to be blocked within three minutes following the PORV closure demand. This question is only relevant for those paths which have a PORV opening and subsequent failure to reclose.

NODE H

Block valve recloses <10 min** after PORV closure demand	Upward paths represent PORV isolation less than ten minutes following the PORV closure demand. Because this question is only relevant for paths which have failed to isolate in less than three minutes, upward paths for this question represent cases where the PORV is isolated between three and ten minutes after the closure demand. Downward paths represent PORVs which are either isolated after ten minutes or those which remain unisolated (or unisolatable after ten minutes)."

*The significance of 3 minutes is that any transient terminated in less than approximately this time will not reach the SI setpoint and is not classified as a small-break LOCA, whereas PORVs unisolated after 3 minutes are considered to be small-break LOCAs.

**The significance of 10 minutes is that, for relatively complex events, operator action may reasonably be expected by this time, and probabilities can be assigned for the success or failure of the operator action. Beyond 10 minutes, it is assumed that no operator action to close the block valve

The branch nodes are then used by Westinghouse to construct an event tree with six possible endpoints. The endpoints as categorized by Westinghouse are given below [5]:

"NR - No PORV or safety valve relief occurs

RR - Relief occurs but valve recloses on demand*

R3 - Relief occurs but valve fails open, reclosed (block valve shut) within 3 minutes of close demand

R10 - Relief occurs, valve fails open, reclosed (block valve shut) within 10 minutes of close demand

RVO - Relief fails open and unisolated within 10 minutes or unisolatable

SVO - Safety valve fails open and remains open."

Using their definition of a small-break LOCA, Westinghouse then sums the path endpoint categories R10 and RVO using all the event tree initiators to obtain the probability of a small-break LOCA from a stuck-open PORV. By adding the endpoint categories of R10 and RVO, Westinghouse is, in essence, calculating the probability that an open PORV remains unblocked for a time period greater than 3 minutes. This is consistent with the Westinghouse definition of small-break LOCA from a stuck-open PORV as one which will cause a safety-injection initiation, since Westinghouse has stated that safety injection will occur in 3 minutes with the PORV open. It should be noted that this definition renders Node H meaningless since by adding R10 and RVO, the probability that the operator fails to shut the block valve in less than 3 minutes is merely multiplied by a factor of one. The sum of the event tree

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*RR is actually made up of two components: the probability of PORV relief and reseat and also SRV relief and reseat.

**p. 14 (Cont.)
will occur for the purposes of this evaluation. (From the standpoint of operator response, Westinghouse classified transients as either simple or complex. Complex transients are those where loss-of-coolant alarms, loss-of-secondary-coolant alarms, or safety-injection alarms could mask the PORV failure or divert the operator to actions or procedures not associated with the PORV. Westinghouse established a normal operator response model which considers a higher operator failure probability for the complex transients than for the simple transients. Westinghouse also established a conservative operator response model which uses the higher operator failure rate for every event, whether a simple transient or a complex transient.)

initiators that ultimately result in path endpoint category SVO represents the probability of a small-break LOCA from a stuck-open safety valve.

3.1.2 Probabilities Data

In order for Westinghouse to quantify the event tree paths that were developed, probability data had to be gathered for each path at each node.

Westinghouse used "conservative engineering judgment" in all cases where sufficient detailed data did not previously exist or could not be obtained for Westinghouse plants. As detailed in Appendix II of Reference 5, the transient characteristic data used to assign the probabilities to Node A and Node D are conservative engineering judgment coupled with the expected pressurizer peak pressure for various transients.

The probability data assigned to the other nodes of the event trees do not deal with the expected plant response. Instead they deal with equipment and operator reliability. Specifically, operator and component data are necessary for:

1. failure of a PORV to open on demand
2. failure of a PORV to reclose on demand
3. failure of a safety valve to reclose on demand
4. failure of an operator to block the PORV within 3 minutes of the time when the PORV would have closed normally
5. failure of an operator to block the PORV within 10 minutes of the time when the PORV would have closed given that item 4 above was unsuccessful.

For the failure of a PORV to open on demand, Westinghouse stated in Reference 5:

> "WASH-1400 estimates the probability of at least one PORV failing to open on a system demand as 3×10^{-5}. This is a valve failure probability and does not consider the factors which cause the signal to fail given legitimate conditions at the process sensor location. A larger failure on demand is used, 1×10^{-2}, to represent a more likely failure mechanism, the failure of a single channel non-redundant control system to yield a demand to the valve, given conditions which should produce such a demand."

For the failure of a PORV to reclose on demand, Westinghouse stated in Reference 5:

"WASH-1400 estimates that the failure of a pressurizer PORV to reclose on demand is 10^{-2}. The data for domestic Westinghouse valve performance shows that there have been over 500 openings to the PORV systems, including both test and operational openings. Although this data may not constitute a complete record of PORV openings, the lack of data indicating no failures to reclose is believed to be accurate. Furthermore, the foreign data for Westinghouse plants would increase the number of valve challenges, but would also increase the number of failures to close to 1. A valve of 10^{-3} failure to close on demand is used for this study."

Westinghouse further clarified in Reference 7:

"WASH-1400 estimates the probability of a PORV failing to reclose on demand to be approximately 10^{-2}, with lower and upper bounds of 10^{-3} and 10^{-1}, respectively. WASH-1400 treats these estimates as the median 5th and 95th percentiles of a lognormal distribution. Given the domestic Westinghouse data presented in Appendix 1 of WCAP-9804, the WASH-1400 distribution can be updated by applying Bayesian techniques. Statistical analysis yields a median estimate of approximately 10^{-3} per demand, which is the value used in the Westinghouse analysis."

For the failure of the safety valve to reclose on demand, Westinghouse stated in Reference 5:

"There have been insufficient challenges to the primary system code safety valves to provide a statistically valid safety valve failure to reclose probability per demand. The same value as is used for the PORV is used for the safety valve in this study."

From Table 3.3 of Reference 5, the following information concerning the probability of operator action to block the stuck-open PORV as a function of time is presented:

"Failure to block the stuck open PORV within 3 minutes (simple transient)(*)	.05

*From the standpoint of operator response, Westinghouse classified transients as either simple or complex. The complex transients are those where loss-of-coolant alarms, loss-of-secondary-coolant alarms, or safety injection associated alarms could mask the PORV failure or divert the operator to actions or procedures not associated with the PORV. Transients T-7, T-8, and T-9 (safety injection initiation, main feedline rupture, and main steamline rupture) were

Failure to block the stuck open PORV within 10 minutes given a failure to isolate within 3 minutes (simple transient)(*)	.01
Failure to block the stuck open PORV within 3 minutes (complex transient)(*)	.80
Failure to block the stuck open PORV within 10 minutes given a failure to isolate within 3 minutes (complex transient).(*)*	.10

Westinghouse further states in Reference 5 regarding operator action that:

"The models above were obtained via interviews with experienced plant operators and simulator trainers. The final models are downward corrected to account for some bias for simulator data, since simulator trainees are expecting events while they have fewer other responsibilities relative to actual control room situations."

3.1.3 Results of Pre-TMI Evaluation

Using the analytical techniques, transient initiator event frequencies, and probabilistic data previously described, a pre-TMI baseline calculation was performed for a Westinghouse-designed plant having a high head safety injection system. Using the previously stated Westinghouse definition for a small-break LOCA from a stuck-open PORV, the frequency of a stuck-open PORV that would be allowed to decrease pressure to the setpoint of the initiation of the safety injection system is 9.4×10^{-6} per reactor-year. The frequency of a stuck-open safety valve for the same plant was evaluated to be 9.6×10^{-6} per reactor-year.

If no operator action to block the stuck-open PORV is assumed, the frequency of a stuck-open PORV would be 1.1×10^{-4} per reactor-year for a pre-TMI Westinghouse-designed plant with a high head safety injection system using the probabilities and frequencies previously outlined.

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*p. 17 (Cont.)
considered complex transients. The remaining transients were considered to be simple transients, i.e., those with relatively few alarms and no abnormal plant behavior other than that associated with the stuck-open PORV.

3.1.4 Summary of Post-TMI Modifications

Westinghouse has made several modifications since the TMI accident to reduce the probability of a stuck-open PORV or safety valve. The modifications, as implemented, affect both the plant design and the operating procedures. The modifications that affect the plant design are generally used to reduce the number of challenges to the PORVs or safety valves by reducing the probability that a given initiator transient event will increase pressure to the PORV opening setpoint. The modifications to the operating procedures are generally used to increase operator awareness to the possibility of a stuck-open PORV, and hence increase the probability of the operator quickly acting to shut the block valve in the event of a stuck-open PORV.

The pressurizer pressure control system (PPCS) was modified in two ways. The control circuit that has been modified operates one of the plant's PORVs and contains a proportional integral derivative (PID) circuit to compensate for a rapidly changing input pressure signal. The derivative time constant in the PID controller for the PORV has been set to the "off" position which effectively removes the derivative (rate of change) action from the controller.

As stated in Reference 5:

> "Removal of the derivative action will decrease the likelihood of opening the PORV since the actuation signal for the valve is then no longer sensitive to the rate of change of pressurizer pressure."

The second change to the PPCS is intended to preclude spurious openings of the PORV. Prior to the change, a safeguard against spurious openings was provided by an interlock in the PORV control circuit which prevented PORV opening when a low pressurizer pressure signal existed. By raising the setpoint of the interlock to 2335 psig (at all 2- and 4-loop plants with 2-out-of-3 low pressurizer pressure safety injection actuation logic), these plants now have the functional equivalent of coincidence PORV opening signals, each signal derived from different pressure channels for any particular valve. Spurious PORV openings are expected to be reduced by an order of magnitude, having eliminated spurious PORV openings due to a single transmitter failure, single pressure channel failure, or single test switch line-up error.

These two modifications to the PPCS will change the transient initiator event frequencies. The other modifications suggested by Westinghouse will increase the probability of the operator blocking a stuck-open open PORV.

As stated in Reference 1, PORVs and safety valves are now required to have direct valve position indication. In addition, the Westinghouse Reference Emergency Operating Instructions (EOIs) have been updated to include notes and specific procedural steps to isolate PORVs. These EOIs have been incorporated into plant-specific procedures which explicitly address the possibility of a stuck-open PORV.

3.1.5 Quantification of the Effects of the Modifications on the Stuck-Open PORV or Safety Valve LOCA Frequency

The removal of the PID circuit from the PPCS affected only transient initiator events that have a rapid pressurization sequence such as large load rejections or loss of feedwater. For those transient initiator events with slow pressurization sequences, the removal of the PID circuit will have no effect. Westinghouse quantified the effect of removing the PID circuit by decreasing the probability of Node A of the event trees by a factor of 2 for those transient initiator events which exhibited large pressure rates.

The change of the pressurizer PORV interlock bistable setpoint functionally gives the PORV actuation system coincidence logic. As noted by Westinghouse in Reference 5:

> "The bistable setpoint change is simulated in the post-TMI baseline by decreasing the frequency of a spurious PORV opening by a factor of 10. This is roughly equivalent to saying that the probability of a common cause failure of the two independent pressure control channels is 10 percent of the probability of the random failure of either channel. Beta factors used in fault tree analyses to model common cause phenomena are rarely as large as 10 percent for similar applications, hence the factor of 10 used is conservative."

The effect of the other modifications is discussed below [5]:

"The combined effect of valve indications and administrative procedures are estimated to decrease the operators's failure rate by a factor of 2, an assumption believed to be conservative. This general rule is applied to both the simple and complex transients since some of the changes affect each of these two types. The basis for a factor of 2 is admittedly

subjective, and was obtained via interviews with simulator instructors who have noticed an increased awareness of plant response to small break LOCAs on the part of license candidates and requalificaton trainees since the TMI accident. Other reactor safety studies have used a factor of 10 for operator reliability benefits due to training in situations where long term operator actions are performed by procedure versus improvisation. The use of a factor of 2 compensates for the short term nature of the demands on the operator and simulates the tendency of a competent operator to thoroughly assess the transient prior to taking actions."

A post-TMI baseline calculation was performed by Westinghouse for a plant with a high head safety injection system. Using the probabilities with the effects of the post-TMI modifications included, the predicted frequency of a small-break LOCA from a stuck-open PORV as defined by Westinghouse is 2.1×10^{-6} per reactor-year. This is a reduction of approximately 78% from the pre-TMI frequency. The post-TMI predicted frequency of a stuck-open safety valve is 4.9×10^{-6} per reactor-year. This is a reduction of approximately 49% from the pre-TMI frequency.

If it is assumed that no operator action is taken to block the stuck-open PORV, the predicted frequency of a stuck-open PORV is 4.6×10^{-5} per reactor-year. This number shows an approximate reduction of 58% when compared to the pre-TMI frequency. It is signficant since it reflects the effect of the post-TMI hardware modifications without using the subjective assumptions pertaining to increased operator awareness and training.

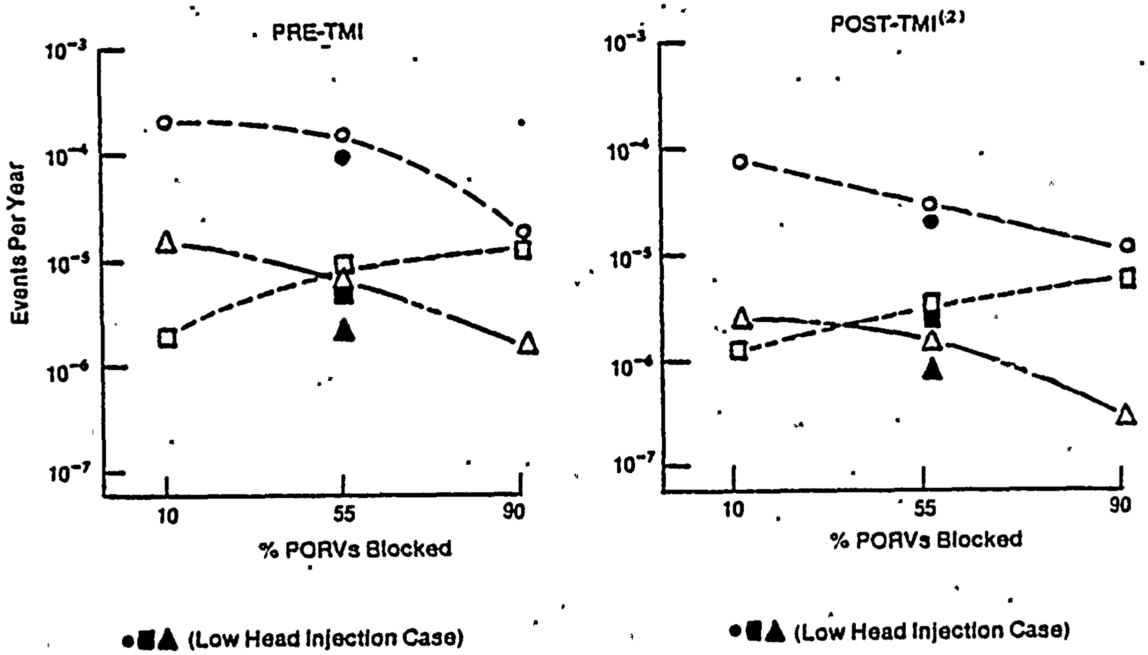
3.1.6 Sensitivity of Results

In Reference 5, Westinghouse shows the flexibility of the event tree as a probabilistic analysis tool, by varying the probabilities at several event tree branch nodes to assess the predicted outcome frequencies sensitivity to various conditions. Included as the variables are:

1. plants with high-head and low-head safety injection systems
2. the percentage of operating time that the PORV is blocked
3. operator response.

The results of these studies are summarized in Figures 3A and 3B.

Baseline Case (1)



Legend:

o PORV Stuck Open: PORV opens and fails to reclose. No credit taken for operator action.

Δ Small-Break LOCA PORV: PORV opens and fails to reclose. No operator action to terminate PORV discharge for at least 3 minutes.

□ Small-Break LOCA SRV: SRV opens and fails to reclose.

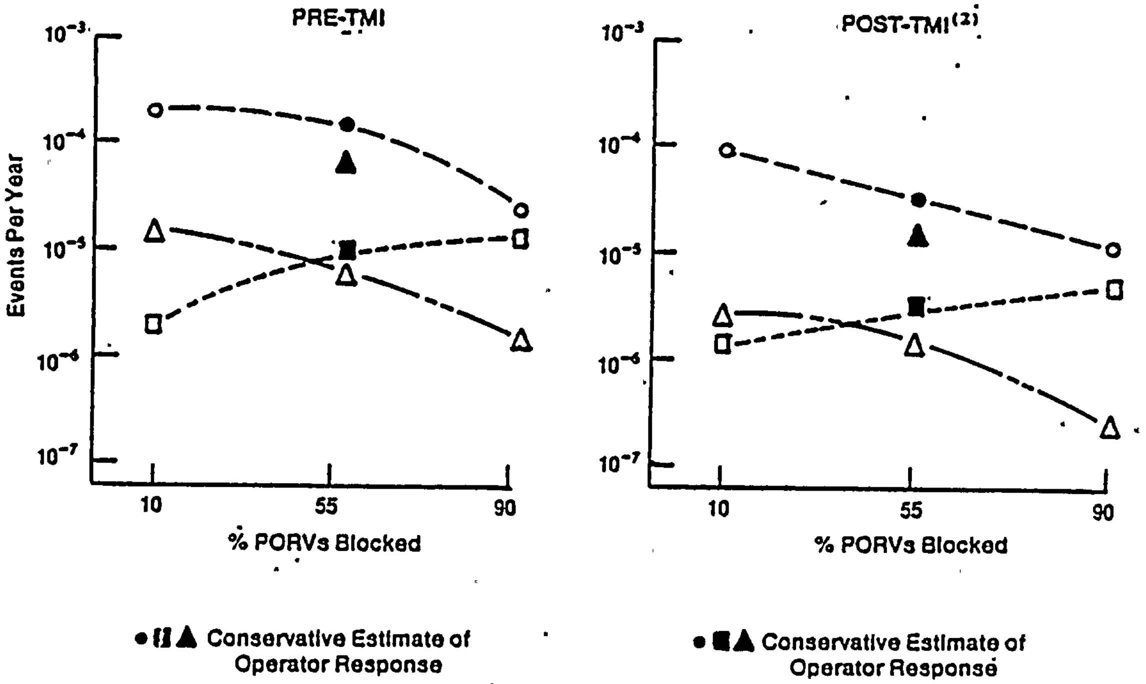
Notes:

1. The baseline case assumes plants with high-head safety-injection systems (i.e., sufficient safety-injection pressure to challenge open the PORVs) and the normally expected operator response model. Results of the analyses of the baseline case are shown for the range of conditions from block valves shut 10% of the time to 90% of the time. Also shown are the results of the study with the block valves shut 55% of the time for the low-head safety-injection plants (i.e., insufficient safety-injection pressure to challenge open the PORVs).

2. See Section 3.1.4 of this report for a complete discussion of the Westinghouse post-TMI modifications.

Figure 3A. Summary of Results for Westinghouse-designed Plants (High-head vs. Low-head Plants with the Expected Operator Model)

Baseline Case [1]



Legend:

○ PORV Stuck Open: PORV opens and fails to reclose. No credit taken for operator action.

Δ Small-Break LOCA PORV: PORV opens and fails to reclose. No operator action to terminate PORV discharge for at least 3 minutes.

□ Small-Break LOCA SRV: SRV opens and fails to reclose.

Notes:

1. The baseline case assumes plants with high-head safety-injection systems (i.e., sufficient safety-injection pressure to challenge open the PORVs) and the normally expected operator response model. Results of the analyses of the baseline case are shown for the range of conditions from block valves shut 10% of the time to 90% of the time. Also shown are the results of the study with the block valves shut 55% of the time for the condition which assumes the more conservative operator response mode.

2. See Section 3.1.4 of this report for a complete discussion of the Westinghouse post-TMI modifications.

Figure 3B. Summary of Results for Westinghouse-designed Plants (High-head Plants Showing Expected and Conservative Operator Response Models)

The sensitivity analysis demonstrates that the reduction in PORV LOCA frequency due to post-TMI modifications for low head plants is essentially identical for low head and high head plants. The results also indicate that the baseline analysis does apply to plants which deviate from the average block valve closure rate. Finally, if operator action prior to 3 minutes is assumed, a more conservative operator model* for mitigating the effects of a stuck-open PORV will result, but the actual LOCA frequency from a stuck-open PORV will remain essentially unchanged.

3.1.7 Conclusion on the Completeness of the WOG Report

The Westinghouse Owners Group Report provides an analysis which supports the conclusion that an automatic PORV isolation system is not required. The report documents the various actions taken to decrease the probability of a small-break LOCA due to a stuck-open PORV or safety valve. The analysis considered operator error, reliability of the PORV block valve, and initiating events that result in an overpressurization. The analysis did not consider depressurization events that actuate high pressure injection and require operator action to prevent challenges to the PORV during recovery. The report has provided data to support the quantification of the event tree paths at each node. The report includes an analysis of the safety valve challenge rate. However, instead of compiling operational data regarding safety valves for use in determining safety-valve failure rates, the WOG has cited a lack of historical data to permit quantification. Where appropriate, operational data were used. The report has not quantitatively evaluated the effect of an automatic PORV isolation system, but has provided a qualitative discussion.

With regard to multiple cycles of multiple PORVs or SRVs, the report notes that a single cycle of a single relief valve, per event, was

*Westinghouse established a normal or expected operator response model which provided one operator failure rate for simple transients and a higher failure rate for complex transients (defined as those transients where loss-of-coolant or safety-injection alarms might divert operator action from the PORV). In the conservative operator model, Westinghouse uses the higher failure rate (i.e., the complex transient failure rate) for all transients, whether simple or complex.

considered. The report states that multiple cycles of multiple valves are possible, although not probable, but does not further quantify or account for this possibility. In addition, the report does not address events where the operator is called upon the manually operate the PORV.

In summary, the WOG Report is complete with the following exceptions:

- o Depressurization events were not considered as initiating events
- o Operational historical data were not used to compile safety-valve failure rates
- o The effect of an automatic PORV isolation system was qualitatively rather than quantitatively discussed.
- o Multiple cycles of multiple PORVs or SRVs were not included in the analysis.
- o Situations where the operator manually operates the PORV were not considered.

3.2 EVALUATION OF THE WOG REPORT SUBMITTED IN RESPONSE TO NUREG-0737, ITEM II.K.3.2

The evaluation of the information reviewed in Section 3.1 of this report, as well as other information pertinent to the stuck-open PORV or safety valve topic, form the basis of this section.

3.2.1 Evaluation of Licensee's Definition of a Small-Break LOCA

The desired outcomes of the event trees used by Westinghouse in Reference 5 are those outcomes that result in a small-break LOCA due to a stuck-open PORV or safety valve. Westinghouse stated in Reference 5 that, "A steam release from the PORV(s) will be considered a small break LOCA if the magnitude and duration is sufficient to automatically actuate safety injection on low pressurizer pressure."

Using this definition, Westinghouse has further stated that [5]:

"A transient which results in a PORV opening and subsequent depressurization is not classified a small-break LOCA if the PORV is closed or blocked

(automatically or manually) prior to safety injection actuation on low pressurizer pressure. Similarly, a PORV leak or incomplete closure would not constitute a small-break LOCA unless the primary pressure and level control system failed to maintain pressure or inventory, resulting in an eventual actuation of safety injection."

Westinghouse justifies the definition by stating that [5]:

"This definition is meant to distinguish between leaks which can be dealt with via technical specification or administrative procedures, and the more relevant transients which require the use of the Emergency Operating Procedure."

Using this definition for a small-break LOCA from a stuck-open PORV, the probabilities for PORV closure or blocking due to operator action affect the probability of the occurrence of a small-break LOCA caused by a stuck-open PORV. Citing the Westinghouse report, WCAP-9601 [10], "Report on Small Break Accidents," Westinghouse states [5]:

"For a loss of all feedwater transients, the time duration between the initial pressure decrease below the PORV closure setpoint and the initiation of safety injection on low pressurizer pressure is approximately 2 to 3 minutes."

It is further clarified that the analysis in Reference 10 was performed to obtain the approximate time for safety injection system actuation assuming the failure of a single PORV to close for a modern 4-loop plant with a power rating of 3425 Mw(t) following a loss of feedwater transient with a reactor trip occurring on steam generator low-low level, well after the loss of feedwater initiated the transient.

Westinghouse uses this study to justify the assumption that if the stuck-open PORV(s) remain unblocked for longer than 3 minutes, the event will be a small-break LOCA according to their definition.

In its most literal sense, a small-break LOCA from a stuck-open PORV or safety valve is in progress from the instant that a PORV or safety valve fails to reseat on demand. Nevertheless, the consequences of a blowdown being extended for an additional minute or two before reseating occurs, or before a PORV block valve is shut, may only result in adding additional water level to the pressurizer relief tank and requiring some additional time to recover

pressurizer level and pressure to the operating range through normal CVCS makeup. On the other hand, if the magnitude or duration of the excess blowdown is sufficient to initiate safety injection, the consequences are greatly compounded and emergency procedures will be required to restore a steady-state plant condition. For the purpose of this analysis, therefore, defining a small-break LOCA from a stuck-open PORV or safety valve as being contingent upon the initiation of safety injection is logical and takes credit for the fact that the operator has the capability to mitigate the effect of a stuck-open PORV (shutting the block valve) or that the blowdown may be slightly extended before the valve actually reseats.

In view of the Westinghouse statement that safety injection will be initiated on low pressurizer pressure in 2 to 3 minutes for all loss of feedwater transients, any stuck-open PORV or safety valve which is not terminated in 3 minutes constitutes a small-break LOCA. Westinghouse implements this definition in the analysis by adding the path endpoints R10 (PORV blocked within 3 to 10 minutes) and RVO (PORV not blocked within 10 minutes) in the case of a PORV and by considering the endpoint SVO (safety valve stuck open) in the case of the SRV. This procedure makes proper use of the definition and is considered to be valid. Furthermore, although not strictly covered by the word definition, the procedure accounts for PORV openings initiated by safety-injection operation (high-head plants) which are not terminated within 3 minutes.

3.2.2 Evaluation of the Means Available to Terminate a Small-Break LOCA

When discussing the means available to terminate a small-break LOCA, a distinction must be made between the small-break LOCAs caused by a stuck-open PORV and the small-break LOCAs caused by a stuck-open safety valve.

The American Society of Mechanical Engineers (ASME) Boiler and Pressure Vessel Code requires the reactor coolant system to be protected from overpressure conditions. The primary safety valves provide the ASME code required overpressure protection. In accordance with the ASME code, these

valves cannot have a blocking valve; therefore, the mitigation of a small-break LOCA from a stuck-open primary safety valve is not possible.

The PORVs in Westinghouse plants are provided to mitigate overpressure conditions which challenge the safety valves and to give the plant a degree of operational flexibility. The PORVs have blocking valves that can be remotely operated; therefore, the mitigation of a small-break LOCA from a stuck-open PORV is possible.

The methods available to mitigate the consequences of a stuck-open PORV require the use of the block valve. The primary method used by Westinghouse plants is operator action to close the block valve and isolate the PORV if the PORV sticks open. The second alternative method would be an automatic PORV isolation system as discussed in NUREG-0737, Item II.K.3.1. The reliability of both of these methods to ultimately block the stuck-open PORV is of the same order of magnitude. The major difference between the two mitigation methods is the time required for block valve actuation to occur and the stuck-open PORV to be blocked.

The automatic PORV isolation system, if functioning properly, would rapidly shut the block valve to isolate the stuck-open PORV once the reactor coolant system pressure had decreased below the PORV closure setpoint. Without a specific automatic PORV isolation system to evaluate, only an order of magnitude estimate can be made of the probability of this system to function on demand. Since it would be a system of comparable characteristics and reliability to the PORV itself, an order of magnitude estimate for the automatic PORV isolation system to fail on demand would be 1×10^{-2} per demand. This estimate is based on an evaluation similar to the discussion given in Reference 5 for estimating the failure of a PORV to open for a pressure above the opening setpoint. The predominant contributor to this failure rate is the failure of the automatic closure signal to reach the motor operator of the valve. This failure for a single channel non-redundant control signal is approximately 1×10^{-2} per demand from Reference 5.

As estimated by Westinghouse in Reference 5, with the post-TMI modifications and procedure in place, the failure rate of the operator to shut the

block valve within 3 minutes after the PORV sticks open during a simple transient* is 2.5 x 10^{-2} per demand. An independent calculation using the techniques of NUREG-CR/1278 [12], "Handbook of Human Reliability Analysis with Emphasis on Nuclear Power Plant Applications," yields an expected operator failure rate of 1.5 x 10^{-2} per demand, which confirms that of the failure rate used by Westinghouse is reasonable. This confirmation also shows that neither of the two primary methods of mitigating a small-break LOCA is a significant improvement compared to the other in terms of reliably mitigating a small-break LOCA from a stuck-open PORV.

3.2.3 Evaluation of Actions Taken to Decrease the Frequency of a Small-Break LOCA from a Stuck-Open PORV

The methods noted in Section 3.2.2 of this report are used to mitigate the effects of a small-break LOCA from a stuck-open PORV. To actually reduce the frequency of a small-break LOCA from a stuck-open PORV:

1. the frequency of demands for the PORV to open must be reduced and/or

2. the failure rate of the PORV to close on demand must be reduced.

The post-TMI Westinghouse modifications have attempted to decrease the frequency of a stuck-open PORV by reducing the number of demands for the PORV to open. From historical data gathered by Westinghouse, the number of actual PORV opening events, pre-TMI, was approximately 0.23 per reactor-year. The post-TMI actual PORV opening event rate has been approximately 0.12 per reactor-year, showing a reduction by a factor of 2. It should also be noted that these rates compare favorably with the transient-related PORV opening rates predicted by the Westinghouse event trees. The Westinghouse predicted pre-TMI and post-TMI transient-related PORV opening rates are 0.12 and 0.05 per reactor-year, respectively.**

*For a definition of simple and complex transients, see the footnote on page 17.

**For a discussion of the deviation of this prediction, see Table 7 on page 53.

The second method of reducing the frequency of a small-break LOCA from a stuck-open PORV is to reduce the failure rate of the PORV to reclose once the PORV has opened on demand. Although Westinghouse did not make any recommendations on improving the reliability of the PORV to reclose once it has opened on demand, several recent studies have attempted to examine PORVs to determine if problems with the PORV and safety valves exist, and if problems do exist, to propose methods for correcting the existing deficiencies. Although not conclusive, ALO-1005 [13]," An Analysis of the Reliability of Light Water Reactor Power-Actuated Pressure-Relieving Valves and Safety (Relief) Valves and Their Component Parts Using the Nuclear Plant Reliability Data System (NPRDS)," attempts to recover and use all available historical data to provide a quantification of the failure rate and mean-time-to-failure of these valves as they contributed to the unavailability and downtime of the plants. In addition, this study developed a functional-element analysis code to describe the components of the valve by system function.

The EPRI Research Project V102 is part of an ongoing program conducted by Electric Power Research Institute (EPRI) to respond to the NRC recommendation documented in NUREG-0737, Item II.D.1.A, "Performance Testing of BWR and PWR Safety and Relief Valves." When completed, this project should further aid in reducing the failure rate of PORVs and safety valves to close once they have been demanded to open.

These and other studies may contribute to reducing the frequency of a small-break LOCA from a stuck-open PORV or safety valve.

3.2.4 Evaluation of Data Sources and Usage

The results of the study are primarily dependent on two data points. These data points are:

1. the failure rate of the PORV or safety valve to close once it has been demanded to open and

2. the frequency of the transient initiator events that demand open the PORVs or safety valves.

Westinghouse collected operational data for pressurizer PORVs and safety valves from the utilities comprising the Westinghouse Owners Group (WOG). The information collected included the known challenges and failures of PORVs and safety valves, as well as the causes of the events associated with the valve openings. Also included was the amount of plant operating time during which the PORVs were isolated.

Westinghouse used the following definition in accumulating the data [5]:

> "Failure is defined as the failure of the valve to close. Valve malfunctions (e.g., leakages, failure to open upon damand, etc.) have not been addressed."

Westinghouse showed that there had been no domestic failure of PORVs in 575 openings. Of these 575 openings, 37 openings occurred during pre-operational tests, 163 openings occurred during plant operation, and the remaining 375 openings occurred during special operational test openings with the PORV block valve closed. It appears that Westinghouse used all of these PORV openings in performing a statistical analysis using Bayesian techniques that yielded a median estimate of the failure rate of the PORV to close of 1×10^{-3} per demand. The Bayesian technique used by Westinghouse for modifying a prior log-normal distribution with posterior data (both pre- and post-TMI) collected subsequent to the formulation of the prior distribution has been verified and is a well documented statistical method.

It can be argued, however, that for conservatism the 375 special operational test openings should not be included in the data base. Since the PORV would have no flow through it when the block valve is shut, the PORV would not be subject to the mechanical vibration and thermal stresses caused by flow through the PORV. It can also be argued that rather than using the prior distribution of WASH-1400, and updating the WASH-1400 distribution with the Westinghouse operational data, Westinghouse should have used the data gathered from the WOG to determine a new failure rate. If this had been done, however, and only the 200 operational openings of the PORV considered, using an upper single-sided attributes technique at the 90% confidence level, a PORV failure rate on demand would be determined to be 1.1×10^{-2} per demand.

Furthermore, subsequent to the evaluation performed by Westinghouse in Reference 5, a steam generator tube rupture event occurred at the R. E. Ginna Nuclear Power Plant on January 25, 1982, as described in NUREG-0909 [14], during which the PORV stuck open. Although it is not rigorously valid statistically to include only this single PORV failure in the WOG data base without including all the other successful PORV cyclings that have occurred since the publication of Reference 5, if done, a failure rate of 1.9×10^{-2} per demand can be calculated using an upper single-sided attributes technique at the 90% confidence level. If this failure rate of 1.9×10^{-2} per demand is used as the failure rate to reclose for both the PORV and the safety valve, and the Westinghouse evaluation of Reference 5 recalculated, the Westinghouse post-TMI expected frequency of a small-break LOCA from a stuck-open PORV or safety valve is still less than 1×10^{-3} per reactor-year as follows:

	Failure Rate of 1.9×10^{-2}/demand, Post-TMI Baseline Case, Expected Operator Response	Failure Rate of 1.9×10^{-2}/demand, Post-TMI Baseline Case, Conservative Operator Response
Small-Break LOCA from Stuck-Open PORV	4.0×10^{-5}/Rx-yr	2.5×10^{-4}/Rx-yr
Small-Break LOCA from Stuck-Open SRV	9.3×10^{-5}/Rx-yr	9.3×10^{-5}/Rx-yr

For the data used in determining the expected frequency of the initiator transient events, Westinghouse used Reference 11 when the event was relatively frequent. For initiator transient events where no historical data existed, conservative engineering judgment using the best source of data available was made by Westinghouse in determining the frequency of the initiator transient events. The numbers used by Westinghouse have been confirmed with the data available in Reference 11.

While there is no rigorous method available to confirm or deny the validity of a substantial portion of the input data used by Westinghouse, particularly where engineering judgment has been applied, certain checks have been made to either affirm the general approach or identify obvious inconsis-

tencies. Three such checks are discussed in the following subsections. The first compares various initiator transients which are similar in nature or have a similar effect on plant operation in order to determine whether they have been treated in a consistent manner and whether there is technical rationale for the distinctions made. The second evaluates Westinghouse's handling of the differences between units with high-head and low-head safety injection. The third evaluates the changes in data between the pre-TMI and post-TMI plant conditions.

3.2.4.1 Comparison of Similar Events

Initiator transients T-1 through T-6 are load rejection transients (turbine trip, turbine trip due to loss of feedwater, MSIV closure, etc.). As can be seen in Table 2, these transients are handled in an identical manner with three exceptions: (1) the initiator frequencies themselves, (2) the probability of exceeding the PORV setpoint (P(A)), and (3) the probability of exceeding the SRV setpoint (P(D)). The probability of exceeding the setpoints is largely a function of steam generator level, availability of the steam dump, elapsed time between turbine trip and reactor trip, and initial power level. The transient with the highest likelihood of exceeding PORV and SRV setpoints is T-6 (MSIV closure), in which there is no anticipatory reactor trip, steam flow is abruptly terminated, and the steam dump is isolated. The transient next most likely to lift the PORV and SRVs is T-5 (large load rejection without direct reactor trip). Again, there is no anticipatory reactor trip in this case, but since the steam dump is available and since less than full load rejection is postulated, probability values of one-half those of T-6 have been used. (Note: the value of 0.01 for P(A) of T-5 is in error; it should read 0.1.) Transients T-1 through T-4 are least likely to lift the PORV and SRVs because there is an anticipatory reactor trip and the steam dump is available in each of these cases. These four transients are treated in an identical manner, except for the initiator frequency. In the case of initiator frequencies, the frequency of T-1 exceeds that of T-2 which exceeds that of T-3. This is logical since each suceeding event requires a more degraded electrical power status: T-1 involves normal loss of feedwater;

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Table 2. Summary of Frequency/Probability Data for Pre-TMI Baseline

	Frequency (R-yr)$^{-1}$	P(A)*	P(B)*	P(C)*	P(D: B or C)	P(D: B and C)	P(E)*	P(F)*	P(G)*	P(H)*
T1	3.0	.02	.55	10^{-2}	.01	.001	10^{-3}	10^{-3}	.05	.01
T2	0.27	.02	.55	10^{-2}	.01	.001	10^{-3}	10^{-3}	.05	.01
T3	7.0(-6)	.02	.55	10^{-2}	.01	.001	10^{-3}	10^{-3}	.05	.01
T4	1.0	.02	.55	10^{-2}	.01	.001	10^{-3}	10^{-3}	.05	.01
T5	1.0	.01	.55	10^{-2}	.10	.01	10^{-3}	10^{-3}	.05	.01
T6	0.07	.20	.55	10^{-2}	.20	.02	10^{-3}	10^{-3}	.05	.01
T7A	.01	.25	.55	10^{-2}	.10	.001	10^{-3}	10^{-3}	.80	.10
T7B	.01	.001	.55	10^{-2}	.001	.001	10^{-3}	10^{-3}	.80	.10
T8	1.0(-4)	.01	.55	10^{-2}	.01	.001	10^{-3}	10^{-3}	.80	.10
T9A	1.0(-4)	.25	.55	10^{-2}	.10	.001	10^{-3}	10^{-3}	.80	.10
T9B	1.0(-4)	.001	.55	10^{-2}	.001	.001	10^{-3}	10^{-3}	.80	.10
T10	0.03	.001	.55	10^{-2}	.001	.001	10^{-3}	10^{-3}	.05	.01
T11	0.12	.01	.55	10^{-2}	.001	.001	10^{-3}	10^{-3}	.05	.01
T12	0.01	.05	.55	10^{-2}	.01	.001	10^{-3}	10^{-3}	.05	.01
T13	1.0(-3)	.50	.55	10^{-2}	.20	.001	10^{-3}	10^{-3}	.05	.01
T14	0.01	.01	.55	10^{-2}	.001	.001	10^{-3}	10^{-3}	.05	.01
T15	0.02	NA	.55	NA	NA	NA	NA	10^{-3}	.05	.01
T16	0.03	.50	.55	10^{-2}	0.0	0.0	NA	10^{-3}	.01	.01

*(Note: The Westinghouse notation used for the various nodes, P(X), is not consistent and is somewhat confusing. Using the standard notation that an upward path is labeled P(X) and a downward path is labeled P($\overline{X}$), the nodes marked with an asterisk (*) should be labeled P($\overline{X}$)).

T-2 adds a concurrent loss of off-site power; and T-3 adds a concurrent loss of all ac power.

Similarly, transient T-8 (main feedline rupture) is treated as a typical loss of feedwater event with two exceptions: (1) it is treated as a complex transient from the standpoint of operator response (see footnote on p. 28), and (2) the probability of exceeding the PORV setpoint is reduced by a factor of 2, since a feedline break has a higher likelihood of occurring in a cooldown condition (i.e., at low power levels). This latter exception considers the differential-temperature stresses and the pressure stresses in the feedwater piping to be higher during cooldown than during normal operation, increasing the likelihood of a feedline rupture during cooldown. Since reactor power level would be quite low during cooldown, the probability of exceeding the PORV setpoint would be lower under these circumstances.

Events T-11, T-12, and T-13 all involve a loss of reactor coolant flow. Event T-13 (locked or sheared reactor coolant pump rotor) causes the most abrupt loss of flow. Events T-12 (complete loss of flow) and T-11 (partial loss of flow) are progressively less severe. The severity of the system pressure transient is directly related to the abruptness with which flow is lost. Consequently, as shown in Table 2, it is logical that the frequency of occurrence of these transients would be largest in the case of T-11 and smallest in the case of T-13, while the probabilities of exceeding PORV and SRV setpoints (P(A) and P(D)) would be the inverse.

Transients T-7 and T-9 are discussed in the next subsection on safety injection. The remaining four events (T-10, T-14, T-15, and T-16) are all rather unique events. They have been roughly compared to the other events, and no obvious inconsistencies were identified.

In summary, the input data have been scrutinized by comparison of similar events. With the exception of only minor inconsistencies, no situation was revealed which might indicate that the data were not valid or were inappropriately used.

3.2.4.2 High-head vs. Low-head Safety Injection

With regard to the differences in PORV challenges between plants designed with high-head safety injection and those designed with low-head systems, Reference 5 makes the following statement:

> "The safety injection system contributes to the PORV opening frequency for plants equipped with charging/SI (high head) pump systems since the shutoff head of these pumps is greater than the opening pressure of the PORVs and in some cases the safety valves. Plants equipped with safety injection systems having a lower shutoff head will not experience the same pressure transient for those scenarios which initiate SI. Of the sixteen initiators evaluated, transients 7 and 9, the inadvertent SI and the steamline rupture respectively involve the operation of SI. The data in rows 7B and 9B of Table 3.4 is applicable to plants with low head SI, and this data is used to recalculate the pre-TMI and post-TMI baseline cases for low head plants. The results of the calculations are shown in Table 3.B for both pre- and post-TMI assumptions, the data in rows 7B and 9B being the only difference between the high head baseline presented in Tables 3.5 and 3.7. Due to the relatively small initiating event frequencies of events 7 and 9, the overall challenge rate is essentially unchanged for the two plants. However, these transients do contribute to the PORV LOCA frequency and safety valve LOCA frequency, the numbers being higher for high head plants. The reduction in PORV LOCA frequency due to post-TMI modifications for low head plants is essentially identical for low head and high head plants (both approximateley 80%)."

Reference 5 provides the following additional information regarding events 7 and 9:

> "<u>T7A - Safety Injection - High Head Plants</u>
>
> Safety injection actuation, whether it is spurious or caused by an upset in plant parameters, can cause the PORV setpoint to be exceeded on plants equipped with charging/SI systems. Typically the shutoff head of the charging pumps exceeds the safety valve set pressures, so opening the safety valves may be possible if the PORV is not available. The probability that the PORV setpoint is exceeded any time a safety injection actuation occurs has been defined at .25, pre-TMI. If the PORV is blocked there is a somewhat smaller probability that the safety valve will be opened, due to the longer period of time available to turn off SI; a probability of .10 is assigned. If the PORV is available, it is virtually impossible to pressurize the system beyond the PORV set pressure due to design constraints, and a small probability is assigned to the safety valve opening, .001, as was done in T4.

T7B - Safety Injection - Low Head Plants

Because the plants having a low head safety injection design cannot repressurize the RCS to the PORV setpoint, these plants are assigned low probabilities for both the PORV and safety valves opening. The value of .001 is used.

T9A-T9B - Rupture of a Main Steamline

Because the steamline break transient is initially a large cooldown, the overriding consideration in system pressurization to the PORV and safety valve setpoints is the operation of the safety injection system. Therefore, the probabilities of exceeding the PORV setpoint and safety valve set pressure with and without PORVs available is assumed to be the same as the safety injection cases 7A and 7B for high head and low head plants, respectively."

A further review of the input-data to the event trees for calculating small-break LOCA probabilities reveals that the distinctions made between high-head and low-head plants were as follows:

Pre-TMI Condition

Event*	P(A) (PORV Setpoint Exceeded)	Nodes P(D: B or C) (SRV Opens)
T-7A	0.25	0.1
T-7B	0.001	0.001
T-9A	0.25	0.1
T-9B	0.001	0.001

Post-TMI Condition

Event*	P(A) (PORV Setpoint Exceeded)	Nodes P(D: B or C) (SRV Opens)
T-7A	0.13	0.1
T-7B	0.001	0.001
T-9A	0.13	0.1
T-9B	0.001	0.001

*T-7A and T-9A represent high-head plants. T-7B and T-9B represent low-head plants.

It is clear from the foregoing information that the Westinghouse approach to distinguish small-break LOCA probabilities as related to high-head and low-head plants is both logical and consistent. As should be expected, the recurrence frequency of a small-break LOCA from a stuck-open PORV or safety valve will be larger at a high-head plant than at a low-head plant. Since Westinghouse's baseline condition considers a high-head plant, no further evaluation of the low-head plants is necessary.

3.2.4.3 Pre-TMI vs. Post-TMI Calculations

Table 3 shows a comparison of initiator frequency and nodal information that Westinghouse modified to account for PORV hardware or procedural changes as a result of TMI Lessons-Learned. These modifications involve one initiator event frequency (event T-15), the probability of exceeding the PORV setpoint for a specific initiator event (P(A)), and the probability of the block valve's being shut within 3 or 10 minutes of a PORV demand-closing (P(G) and P(H)). An evaluation of Westinghouse's rationale for changing these values follows.

First, the frequency of inadvertent PORV openings (initiation event T-15) has been reduced by an order of magnitude (0.02 to 0.002). This reduction is attributed to the change of PORV interlock bistable setpoint. As discussed previously, this change effectively makes the PORV pressure control signal a redundant signal (coincidence logic), thereby greatly reducing the frequency of inadvertent openings. PORV openings due to transmitter failure, channel failure, and improper test switch line-up have effectively been eliminated. Since the largest number of inadvertent PORV openings is likely to be generated by these types of control-signal failures or errors, a reduction of the initiator frequency from 0.02 to 0.002 is considered to be both appropriate and justified.

With regard to the probablity that the PORV setpoint will be exceeded for any given initiator event (node P(A)), several initiator events which exhibit slow pressurization were not affected by the TMI modifications. These events are:

Table 3. Comparison of Pre-TMI/Post-TMI Nodes and Transient Frequencies

	P(A) (PORV Setpoint Exceeded)		P(G) (Block Valve Fails to Close Within 3 Minutes)		P(H) (Block Valve Fails to Close Within 10 Minutes)	
T-No.	Pre-	Post-	Pre-	Post-	Pre-	Post-
1	0.02	0.01	0.05	0.025	0.01	0.005
2	0.02	0.01	0.05	0.025	0.01	0.005
3	0.02	0.01	0.05	0.025	0.01	0.005
4	0.001	0.0005	0.05	0.025	0.01	0.005
5	0.01	0.005	0.05	0.025	0.01	0.005
6	0.2	0.1	0.05	0.025	0.01	0.005
7A	0.25	0.13	0.8	0.4	0.1	0.05
7B	0.001		0.8	0.4	0.1	0.05
8	0.01	0.005	0.8	0.4	0.1	0.05
9A	0.25	0.13	0.8	0.4	0.1	0.05
9B	0.001		0.8	0.4	0.1	0.05
10	0.001		0.05	0.025	0.01	0.005
11	0.01	0.005	0.05	0.025	0.01	0.005
12	0.05	0.025	0.05	0.025	0.01	0.005
13	0.5	0.25	0.05	0.025	0.01	0.005
14	0.01		0.05	0.025	0.01	0.005
15	NA		0.05	0.025	0.01	0.005
16	0.5		0.05	0.025	0.01	0.005

	Freq. of Transient	
	Pre-	Post-
15	0.02	0.002

T-7B inadvertent safety injection (low-head)

T-9B main steamline rupture (low-head SI)

T-10 CVCS malfunction resulting in increased power

T-14 uncontrolled bank withdrawal resulting in increased power

T-15 inadvertent PORV opening

T-16 excessive SG tube leakage or tube rupture.

For the remaining initiator events, all of which exhibit a high rate of pressurization, the probability of exceeding the PORV setpoint was reduced by a factor of 2. The reason for the factor of 2 reduction is that the PID controller setpoint change has eliminated the possibility of PORV opening on rate compensation. Westinghouse states that the factor of 2 is a conservative estimate obtained by evaluating pressure transients for identical load rejections at different power levels. Reduction of node P(A) values by a factor of 2 is considered to be a reasonable method of accounting for the elimination of rate sensitivity due to the PID controller setpoint change.

Finally, Westinghouse reduced the operator failure rates (P(G) and P(H)) by a factor of 2, saying:

> "The combined effect of valve indications and administrative procedures are estimated to decrease the operator's failure rate shown in Appendix Figure II.1 by a factor of 2, an assumption believed to be conservative. This general rule is applied to both the simple and complex transients since some of the changes affect each of these two types. The basis for a factor of 2 is admittedly subjective, and was obtained via interviews with simulator instructors who have noticed an increased awareness of plant response to small break LOCAs on the part of license candidates and requalification trainees since the TMI accident. Other reactor safety studies have used a factor of 10 for operator reliability benefits due to training in situations where long term operator actions are performed by procedure versus improvisation. The use of a factor of 2 compensates for the short term nature of the demands on the operator and simulates the tendency of a competent operator to thoroughly assess the transient prior to taking actions.".

The history of PORV failures indicates that probably the most significant factor in the operator's ability to take timely block-valve action is effective PORV position indication. The improved valve position indication alone is probably sufficient to justify a factor of two reduction in the

probability of failure to close the block valve. When added to increased operator awareness and other procedural changes, the reduction factor is considered to be conservative.

3.2.5 Evaluation of Licensee's Consideration of Multiple Lifts of the PORV During a Transient

The problem of multiple PORV lifts during a transient was briefly addressed by Westinghouse in Reference 5. Westinghouse stated [5]:

> "Each transient is characterized by a single opening and closing of a PORV. Even using extreme assumptions to perform a bounding calculation (three PORVs open five times per transient) the resulting frequency of the PORV LOCA contributes only 15 percent to the value of 10-3, the median value of a small break LOCA from WASH-1400."

Specifically, the post-TMI expected frequency of a small-break LOCA from a stuck-open PORV with no operator action for a plant with a high-head safety injection system assuming multiple PORV lifts as described above would be 6.9×10^{-4} per reactor-year.* This bounding calculation shows that the expected frequency of a small-break LOCA from a stuck-open PORV is less than the WASH-1400 median frequency of 1×10^{-3} per reactor-year. However, this calculation assumes that the failure rate of the PORV is a constant.

Based on the incidents at the Davis-Besse and R. E. Ginna nuclear plants, there is reason to believe that multiple cycles of the PORV within a relatively short period of time may cause an increase in the failure rate of the PORV. Nevertheless, multiplying by the factor of 15 and also assuming no operator action adds such conservativism to the bounding value of the preceding paragraph that the possibility of an increased failure rate due to multiple cycles should be offset. In addition to this simplified bounding calculation, a detailed bounding value calculation is performed in Appendix B to this report and discussed in Section 3.2.9. This calculation also shows that the probability of a small-break LOCA and stuck-open PORV or safety valve is less than the median frequency for a small-break LOCA of WASH-1400.

*This value is derived by adding the post-TMI baseline endpoints R-3 + R10 + RVO and then multiplying by 15 (3 PORVs each cycling 5 times).

3.2.6 Evaluation of the Consideration of Events Which Require Operator Action to Open the PORV

There are certain situations which make administrative use of the PORV to depressurize the reactor coolant system. The more significant situations are:

1. use of the PORV in the plant recovery from a steam generator tube rupture event

2. use of the PORVs in "feed and bleed" operations in response to inadeqate core cooling (ICC) scenarios (particularly applicable to plants with low-head safety injection systems where manual operation of the PORV is necessary to remove RCS water volume)

3. use of the PORV to vent the reactor coolant system in order to remove non-condensible gases.

In any situation in which the operator wishes to depressurize the reactor coolant system, the operator can use the PORV to accomplish reactor coolant system depressurization. By cycling the PORV open and shut, the operator is able to control the reactor coolant system pressure. As noted in Section 3.2.5 of this report, it appears that relatively rapid repetitive cycling of the PORV can result in increasing the failure rate of the PORV to close when demanded.

Although not specifically addressed by Westinghouse in References 5 and 7, it is concluded that this problem is not a significant contributor to the expected frequency of a small-break LOCA from a stuck-open PORV. The main reason for this conclusion is that in any situation in which the operator is manually cycling the PORV open and shut, the operator would be particularly aware of the position of the PORV and of the rate of change of affected parameters such as pressurizer pressure, level, and temperature. If the PORV were to fail to close on demand (as indicated by PORV position indication or continuing decrease of pressurizer pressure or level), the operator would immediately shut the PORV block valve, terminating the potential small-break LOCA.

For example, the following actual events occurred at the Ginna plant during the steam generator tube rupture event of January 25, 1982, as reported in Reference 14:

"10:07 a.m.

As directed by the SGTR procedure, pressurizer PORV PCV430 controls were manually cycled open and closed twice from the control room. RCS pressure, PRT pressure, level and temperature and PORV valve position indication in the control room demonstrated the valve successfully operated.

10:08 a.m.

Pressurizer PORV PCV430 controls were manually cycled again from the control room and the valve successfully operated.

10:09 a.m.

Pressurizer PORV PCV430 controls were manually cycled again. The valve opened as desired. After the operator placed the controls in the closed position, the valve started to close but then reopened and stuck open.

The operator placed the PORV block valve control switch in the closed position. RCS pressure dropped to about 900 psig; pressurizer level increased rapidly.

10:11 a.m. (about)

PORV block valve PCV516 indicated fully closed; pressurizer level indicated offscale high; safety injection increased RCS pressure."

This event is typical of expected operator response when a PORV which is being cycled, fails.

The limiting component of this scenario will be the motor-operated block valve. The failure rate of a motor-operated valve to operate on demand from NUREG/CR-1363 [15], "Data Summaries of Licensee Event Reports of Valves at Commercial Nuclear Power Plants," is 4×10^{-3} per demand. Therefore, even assuming that the failure rate of the PORV is conservatively estimated at 1.9×10^{-2} per demand and that the frequency of these events is 0.1 per reactor-year (10 times the recorded frequency of a steam generator tube rupture), the contribution of these administratively required operator-induced PORV cyclings and subsequent failures is only 7.6×10^{-6} per reactor-year, which is not a significant contributor to the overall expected frequency of a small-break LOCA from a stuck-open PORV. Further, even considering a large number of multiple cycles (10 or more), the contribution to the overall frequency remains low.

3.2.7 Evaluation of Overcooling Events

The contribution of overcooling events to the total expected frequency of a small-break LOCA from stuck-open PORV or safety valve is discussed and quantitatively evaluated in Appendix A of this report. The generic plant as evaluated in Appendix A is assumed to have a high-head safety injection system that is capable of developing sufficient pressure in the reactor coolant system to challenge (demand open) the PORV(s) and/or safety valves. A generic plant of this design with a high-head safety injection would therefore be the limiting or bounding case to be evaluated for its contribution to the expected frequency of a small-break LOCA from all sources. Based on the calculations shown in Appendix A, it can be concluded that overcooling events which initiate the safety injection system are not a significant contributor to the expected frequency of a small-break LOCA from a stuck-open PORV or safety valve.

3.2.8 Evaluation of Low-Temperature/Overpressure Events

In August 1976, the issue of low-temperature, overpressure protection was raised and licensees initiated procedures and proposed systems to mitigate postulated overpressure events. The main concern was with the low-temperature modes of cooldown and heatup, during which overpressurization could cause brittle fracture of the reactor vessel. In most cases, licensees proposed a manually enabled low-pressure setpoint on the existing PORVs, supplemented by procedures and technical specifications, as the means of preventing overpressurization while at low temperatures.

With the reduced preessure setpoint in effect, transients or plant operations normally associated with the shutdown/cooldown plant can cause PORV actuation (and hence possible small-break LOCA), such as inadvertent operation of the pressurizer heaters or excessive charging. Although not addressed by Westinghouse in Reference 5 or 7, it is considered that the low-temperature, overpressure situation need not be considered with the other transients which can result in a small-break LOCA from a stuck-open PORV. The reasons for this conclusion are:

- When reduced pressure setpoints are in effect, the plant will generally be in a long-term cooling mode using the RHR system. RHR can maintain system water inventory in spite of an open PORV.

- When reduced pressure setpoints are in effect, the operator has less equipment running and can readily diagnose abnormal conditions. The operator is in a less stressful condition and can be expected to react in a positive manner.

- When reduced pressure setpoints are in effect, the plant has been shut down for some period of time and therefore decay heat rates are lower, providing more reaction time before thermal limits are approached.

- The temperature of the coolant released from the PORV under these conditions will normally be such that flashing to steam will not occur. The water will merely be collected in the containment sump.

3.2.9 Comparison of Various Study Results

As fully discussed in the preceding paragraphs of this section, there are numerous ways in which variations can enter a study to determine the expected frequency of a small-break LOCA from a stuck-open PORV or safety valve. Therefore, any absolute comparison of numbers generated by two different studies must be evaluated carefully. As stated by Westinghouse in Reference 5:

> "Because there is no assurance that the aforementioned 10^{-3} accounts for the PORV LOCA frequency in a manner consistent with that used in this evaluation, most importance is placed on the comparison between pre-TMI and post-TMI frequencies."

This evaluation concurs with the above statement by Westinghouse. However, it is also important to note that the expected frequency of a small-break LOCA from a stuck-open PORV or safety valve as calculated by Westinghouse is less than 1×10^{-3} per reactor-year. The statistical methods employed by Westinghouse are valid mathematical treatments of the historical operating data accumulated by the WOG. The event tree used by Westinghouse is a flexible probabilistic analysis tool which allows determination of a sufficiently low expected frequency using various definitions of a small-break LOCA (see Section 3.2.1 of this report).

3.2.10 Evaluation of Results and Conclusions

Appendix B describes the calculations performed to conduct an independent check of the Westinghouse calculations of Reference 5. These check calculations verified the Westinghouse results as follows:

Small-Break LOCA, Baseline High-Head Plant) Case	Westinghouse (Reference 5) $(Rx\text{-}yr)^{-1}$	Independent Check Calculation $(Rx\text{-}yr)^{-1}$
PORV (Pre-TMI)	9.4×10^{-6}	9.9×10^{-6}
SRV (Pre-TMI)	9.6×10^{-6}	9.6×10^{-6}
PORV (Post-TMI)	2.1×10^{-6}	2.6×10^{-6}
SRV (Post-TMI)	4.9×10^{-6}	4.8×10^{-6}

In addition to the check calculations, Appendix B presents the results of independent post-TMI bounding calculations performed to combine the most severe effects of the various sensitivity studies performed by Westinghouse. The bounding calculations considered:

- o Block valves to be 100% open in the case of the PORV and 100% closed in the case of the SRV
- o The conservative operator model (operator response model for the complex transient used for all transients)
- o An increased PORV/SRV failure rate of 1.1×10^{-2} per demand, rather than Westinghouse's rate of 10^{-3} per demand, as discussed in Section 3.2.4 of this report, for all initiator events except T-15
- o A 100% PORV failure probability for event T-15 (inadvertent PORV opening)
- o Multiple cycles of multiple valves (5 cycles of each of 3 valves for all transients except T-15, inadvertent PORV opening).

The bounding calculations showed that even with the conservative assumptions, the post-TMI frequency of a small-break LOCA from either a stuck-open PORV or safety valve remains within the range of WASH-1400 frequencies (10^{-2} to 10^{-4}) for small-break LOCA as follows:

Small-Break LOCA from Stuck-Open PORV	9.4×10^{-3} per rx-yr
Small-Break LOCA from Stuck-Open SRV	1.3×10^{-3} per rx-yr

4. APPLICABILITY

4.1 APPLICABILITY OF THE WOG REPORT TO SPECIFIC WESTINGHOUSE UNITS

In the WOG Report (WCAP-9804), the following statement is made regarding applicability of the generic analysis to specific Westinghouse plants:

> "The analysis has considered Westinghouse plants with either high head or low head safety injection systems, and is generically applicable to all Westinghouse plants which have incorporated the post-TMI hardware and procedural changes relative to stuck-open PORVs. The operational data in Appendix I is composite data and may be referenced by all Westinghouse plants as being representative of plants designed by Westinghouse."

The WOG report also provided Table I.3 (reproduced here as Table 4), which identifies the status of TMI-modification hardware changes as of the time of the report. As can be seen, none of the 28 plants listed had reported complete installation of hardware changes as of that time.

4.2 COMPARISON OF WOG REPORT TO OPERATING DATA

In order to confirm the applicability of the generic report to operating Westinghouse units (assuming TMI modifications installed), a comparison has been made between the model of the WOG report and operational data or information from the various units. The following three areas, which are considered to be the most susceptible to variations between the model and actual plants, were compared:

- o PORV challenge rate
- o block valve status
- o PORV failure rates.

Details of these comparisons are provided below.

4.2.1 <u>PORV Challenge Rate</u>

In Appendix I to the WOG Report itself, certain operational data were provided, including information such as actual PORV operational openings (Table I.1) and plant operating times, PORV operating times, percentage of time PORV block valves are shut, etc. (Table I.2). These tables are included

Table 4. Post-TMI Modifications

	PID CONTROLLER MODIFICATION (DERIVATIVE TIME CONSTANT SET TO OFF)	SETPOINT CHANGE ON PORV INTERLOCK BISTABLES (TYPICALLY FROM 2185 PSIG TO 2335 PSIG)	SAFETY VALVE POSITION INDICATION/FLOW INSTALLED (E.G., ACOUSTIC MONITORING SYSTEM, TEC DIRECT POSITION MONITORING SYSTEM)	SAFETY VALVE POSITION-INDICATING LIMIT SWITCHES REPLACED WITH ENVIRONMENTALLY QUALIFIED LIMIT SWITCHES	PORV POSITION INDICATION/FLOW INSTALLED (I.E., ACOUSTIC MONITORING SYSTEM ON HEADERED DISCHARGE PIPE FROM PORVs TO PRESSURIZER RELIEF TANK)	PORV POSITION-INDICATING LIMIT SWITCHES REPLACED WITH ENVIRONMENTALLY QUALIFIED OR SEALED LIMIT SWITCHES
PLANT #1		X	X		X	X
PLANT #2		X	X		X	X
PLANT #3	X			X		X
PLANT #4	X		X			
PLANT #5		X	X			X
PLANT #6		X	X			X
PLANT #7	X					
PLANT #8			X			
PLANT #9			X			
PLANT #10		X	X			X
PLANT #11	X	X	X		X	
PLANT #12		X				
PLANT #13		X				
PLANT #14	X	X	X	X		X
PLANT #15		X				
PLANT #16		X				
PLANT #17		X				
PLANT #18			X			X
PLANT #19						
PLANT #20						
PLANT #21						
PLANT #22						
PLANT #23	(1)					
PLANT #24	(1)					
PLANT #25		X	X			
PLANT #26						
PLANT #27						
PLANT #28	X	X				

(1) NO RESPONSE PROVIDED TO REFERENCE 6.

here as Tables 5 and 6. Using these data, a correlation was made to the WOG model as follows:

1. A calculation was made to determine the number of PORV openings per reactor-year predicted by the model, using pre-TMI baseline plant values. As shown in Table 7, the model predicts 0.25 PORV openings per year of reactor operation (considering block valves open 100% of the time).*

2. Using information from Tables 5 and 6, a determination of reported PORV openings per year of reactor operation was made for each plant which reported at least one actual PORV opening (Table 8).

3. A comparison was made of reported openings per reactor-year to the predicted frequency of 0.25 (adjusted for site-specific block valve conditions). As can be seen in Table 8, only 4 plants (plant Nos. 3, 7, 13, and 27) exceeded the predicted frequency by a substantial margin (factor of 5 or greater) and only one plant (No. 7) exceeded the predicted frequency by more than a factor of 10.**

In view of this comparison and the extremely low frequency of a small-break LOCA from a stuck-open PORV (baseline case/post-TMI) of the WOG Report (2.1×10^{-6}/reactor-year), it was concluded that, based upon the information provided, only plant No. 7 required further investigation to verify that a plant-specific recurrence frequency for this unit did not exceed the WASH-1400 median recurrence frequency for small-break LOCA of 1×10^{-3}/reactor-year. As shown in the notes to Table 5, however, it appears that the information provided in this table is not complete. Several units never responded to the Westinghouse request which generated Table 5. Consequently, a further investigation of PORV opening history might reveal other units, other than plant No. 7, that need to be evaluated as is done in this report for plant No. 7.

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*See Note 1 to Table 7 for a discussion of the deviation of this value.

**As seen in the notes to Table 5, plant Nos. 1 and 2 did not provide a specific response to Westinghouse (NUREG-0611 data were used), plant Nos. 4, 19, and 20 addressed recent time frame only, and plant Nos. 8 and 9 indicated no specific records existed (NUREG-0611 data were used).

Table 5. PORV Openings

	PREOPERATIONAL TEST (INCLUDING HOT FUNCTIONAL TEST AND NATURAL CIRCULATION TEST) OPENINGS	OPERATIONAL OPENINGS: INTENTIONAL TEST	SPECIAL OPERATIONAL TEST (PORVs CYCLED WITH BLOCK VALVES CLOSED)	INSTRUMENTATION OR PERSONNEL ERROR	COLD SHUTDOWN, WATER SOLID	DRAINING OR VENTING DURING SHUTDOWN	INTENTIONAL OPENING FOR PRESSURE CONTROL	TRANSIENT RESPONSE: FAILURE OF CRIDS, I AND II VITAL POWER SUPPLY INVERTERS; CRIDS WITH SI SIGNAL. RESULTED IN REACTOR TRIP AND LOSS OF PRESSURIZER SPRAY(1)	LOSS OF MAIN FEEDWATER, REACTOR TRIP	REACTOR TRIP (LOW LOW S/G LEVEL) DURING STARTUP WITH MANUAL PRESSURE CONTROL	SEVERE THUNDERSTORM RESULTED IN REACTOR TRIP, SI, AND LETDOWN ISOLATION	LEAK IN TURBINE DEH CONTROL OIL SYSTEM, TURBINE RUNBACK, INCREASING TAVG	STEAM DUMP FUNCTION OR FULL LOAD REJECTION	SHUTDOWN DUE TO LEAKING PRESSURE TRANSMITTER	FEEDWATER VALVE REGULATOR FAILURE, REACTOR TRIP	STEAM DUMP MALFUNCTION, REACTOR TRIP
PLANT #1		1(1)		1(1)	1(1)			2(1)								
PLANT #2																
PLANT #3									1	1	1	1				
PLANT #4					1(2)											
PLANT #5						25										
PLANT #6						25										
PLANT #7	21	8					2		6				7	2	2	7
PLANT #8		7(3)		1(3)									2(3)			
PLANT #9																
PLANT #10																
PLANT #11																
PLANT #12	2	9														
PLANT #13	2															
PLANT #14	4															
PLANT #15	2		375				2									
PLANT #16	2															
PLANT #17				1												
PLANT #18				1												
PLANT #19		5(2)														
PLANT #20																
PLANT #21																
PLANT #22	3															
PLANT #23	1															
PLANT #24																
PLANT #25																
PLANT #26																
PLANT #27																
PLANT #28																

Table 5 (Cont.)

OPERATIONAL OPENINGS

TRANSIENT RESPONSE

	INVERTER FAILURE, REACTOR TRIP	REACTOR TRIP DUE TO LOW STEAM PRESSURE	EHC MALFUNCTION OR LOSS OF EH OIL, REACTOR TRIP	MAIN STEAM ISOLATION VALVE FAILURE OR CLOSURE, REACTOR TRIP	HIGH STEAM FLOW, REACTOR TRIP, SI	SHUTDOWN DUE TO NOISE IN GENERATOR	SHUTDOWN DUE TO LOSS OF RCP COOLING WATER	BLACKOUT DUE TO TRANSFORMER FAILURE	PRESSURIZER PRESSURE TRANSMITTER FAILURE (FULL SCALE)	STEAM GENERATOR TUBE RUPTURE	GENERATOR BREAKER OPENED	LOSS OF, FAILURE OF, OR GROUNDED VITAL BUS	LOSS OF AC
PLANT #1													
PLANT #2													
PLANT #3													
PLANT #4													
PLANT #5													
PLANT #6													
PLANT #7	3	1	2	5	2	1	2	4					
PLANT #8													
PLANT #9													
PLANT #10													
PLANT #11													
PLANT #12													
PLANT #13			2						2	7			
PLANT #14											2		
PLANT #15													
PLANT #16													
PLANT #17													
PLANT #18													
PLANT #19													
PLANT #20													
PLANT #21													
PLANT #22													
PLANT #23													
PLANT #24													
PLANT #25													
PLANT #26													
PLANT #27												7	1
PLANT #28													

(1) NO RESPONSE PROVIDED TO REFERENCE 5; NUREG-0611 DATA (TABLE VI-4) USED.

(2) RESPONSE TO REFERENCE 5 ADDRESSED RECENT TIME FRAME ONLY; NUREG-0611 DATA (TABLE VI-4) USED.

(3) RESPONSE TO REFERENCE 5 INDICATED NO SPECIFIC RECORDS; NUREG-0611 DATA (TABLE VI-4) USED.

Table 6. PORV and Safety Valve Operational Data (Number of Valves, Operating Times, Operation Time with PORVs Isolated)

	NUMBER OF PORVs	NUMBER OF SAFETY VALVES	PLANT OPERATING TIME EXCLUDING OUTAGE TIME (HOURS)(1)	PORV OPERATING TIME (HOURS)(1)	SAFETY VALVE OPERATING TIME (HOURS)(1)	% OF POWER OPERATION TIME WITH ONE PORV ISOLATED	% OF POWER OPERATION TIME WITH TWO PORVs ISOLATED	% OF POWER OPERATION TIME WITH THREE PORVs ISOLATED
ANT #1	3	3	33012	99036	99036	90	10	0
ANT #2	3	3	15929	47787	47787	10	0	0
ANT #3	2	3	16166	32332	48498	74/18(2)	1	(3)
ANT #4	2	3	52039	104078	156117	-	100	(3)
ANT #5	2	3	42478	84956	127434	-	100	(3)
ANT #6	2	3	38202	76404	114606	-	100	(3)
ANT #7	3	3	15991	47973	47973	70	50	10
ANT #8	2	3	51236	102472	153708	50	5	(3)
ANT #9	2	3	45107	90214	135321	50	5	(3)
ANT #10	2	3	42601	85202	127803	-	100	(3)
NT #11	2	3	24418	48836	73254	50/8(2)	8	(3)
NT #12	2	2	46526	93052	93052	23	0	(3)
NT #13	2	2	43301	86602	86602	14	0	(3)
NT #14	2	3	22956	45912	68868	10	0	(3)
NT #15	2	3	15377	30754	46131	60	25	(3)
NT #16	2	2	(4)	(4)	(4)	60	25	(3)
NT #17	2	2	51926	103852	103852	1/1(2)	1	(3)
NT #18	2	2	48981	97962	97962	20	0	(3)
NT #19	2	3	41684	83368	125052	-	100	(3)
NT #20	2	3	35180	70360	105540	-	100	(3)
NT #21	2	3	16330	32660	48990	20	4	(3)
NT #22	2	3	(4)	(4)	(4)	(4)	(4)	(3)
NT #23	2	2	55548	111096	111096	(5)	(5)	(3)
NT #24	2	2	58625	117250	117250	(5)	(5)	(3)
NT #25	2	2	45971	91942	91942	50	10	(3)
NT #26	1	2	48491	48491	96982	0	(3)	(3)
NT #27	2	3	56156	112312	168468	-	100(6)	(3)
NT #28	2	3	(4)	(4)	(4)	(4)	(4)	(3)
AL			964231	1944903	2493324			

BASED ON WESTINGHOUSE AVAILABILITY DATA THROUGH 10/80; AS OF 10/80 APPROXIMATELY 181 REACTOR YEARS OF OPERATION HAVE BEEN ACCUMULATED.

% OF TIME EACH PORV IS ISOLATED.

NOT APPLICABLE.

LITTLE OR NO OPERATING EXPERIENCE.

NO RESPONSE PROVIDED TO REFERENCE 6.

PORV BLOCK VALVES ARE NORMALLY CLOSED, OPEN ON SAME SIGNAL AS PORVs.

Table 7. PORV Openings per Reactor Year (Pre-TMI)

Initiator Event	Event Frequency* $(\text{Reactor-year})^{-1}$	PORV Setpoint* Exceeded	PORV Openings $(\text{Reactor-year})^{-1}$
T-1	3	0.02	0.06
T-2	0.2	0.02	4×10^{-3}
T-3	7×10^{-6}	0.02	1.4×10^{-7}
T-4	1	0.001	1×10^{-3}
T-5	1	0.1	0.1
T-6	0.1	0.2	0.02
T-7A	0.05	0.25	1.25×10^{-2}
T-7B	0.05	0.001	
T-8	2×10^{-3}	0.01	2×10^{-5}
T-9A	2×10^{-3}	0.25	5×10^{-4}
T-9B	2×10^{-3}	0.001	
T-10	0.03	0.001	3×10^{-5}
T-11	0.12	0.01	1.2×10^{-3}
T-12	0.01	0.05	5×10^{-4}
T-13	1×10^{-3}	0.5	5×10^{-4}
T-14	0.01	0.01	1×10^{-4}
T-15	0.02	Not Applicable	0.02
T-16	0.06	0.5	0.03
		Total	0.25 (see Notes 1 and 2)

*For a discussion of values used in this table, see Appendix B, pages B-1 through B-3.

Notes:

1. This table indicates a PORV opening rate of 0.25 openings per reactor-year with the block valves open 100% of the time. Considering block valves to be open only 45% of the time (as done in the WOG report), the PORV challenge rate becomes 0.1125 per reactor-year (0.25 x 0.45). The WOG report states that the annual PORV opening rate is 0.12 openings per reactor-year based upon the calculation of the value RR (relief and reseat) (see Table B-3). (RR in this calculation includes a small component attributed to relief and reseat of the safety relief valve.) For the purposes of this comparison, however, an opening rate of 0.25 per reactor-year will be used, which will be adjusted for the actual block valve conditions at the specific plant as reported in Table 6.

2. A calculation similar to that of this table was performed for the post-TMI condition. This calculation indicated a post-TMI PORV opening rate of 0.13 per reactor-year (with block valves open 100% of the time). This opening rate confirms the 0.05 per reactor-year opening rate stated in the WOG report when considering the block valves to be open 45% of the time and also

Table 8. Comparison With Operating Data

Plant	Reported Unintentional PORV Openings (Table 5)	Hours Operation (Table 6)	Openings Per Reactor-year	Ratio of Openings to the WOG Prediction*	Block Valve Positions % Open (Table 6)	Adjusted Ratio of Openings to WOG Prediction
1	3	48,941	0.54	2.16	0.9	1.94
2						
3	4	16,166	2.17	8.68	0.99	8.59
4	0					
5	0					
6	0					
7	44	15,991	24.1	96.4	0.5	48.2
8	2	96,343	0.18	0.72	0.95	0.68
9						
10	0					
11	0					
12	0					
13	11	43,301	2.23	8.92	1.0	8.92
14	2	22,956	0.76	3.04	1.0	3.04
15	0					
16	0					
17	1	51,926	0.17	0.68	0.99	0.67
18	1	48,981	0.18	0.72	1.0	0.72
19	0					
20	0					
21	0					
22	0					
23	0					
24	0					
25	0					
26	0					
27	8	56,156	1.25	5.0	1.0	5.0
28	0					

*Based upon an opening rate of 0.25 openings per reactor-year. See the note on Table B-7.

Note 2, p. 53 (Cont.)

shows an approximate 2 to 1 reduction in PORV openings as a result of the TMI modifications. Since the information in Tables 5 and 6 is essentially pre-TMI information, however, the 0.25 openings per reactor-year calculated from the pre-TMI information is used for the comparison of Table 8.

As shown in Table 8, plant No. 7 reported a total of 44 unintentional openings in 15,991 hours of operation, for a frequency of 24.1 PORV openings per reactor-year. Although the transient categories of Table 2 do not correlate exactly to the 16 transient categories of the WOG analysis, the 44 operational openings of plant No. 7 were classified into the category of the WOG Report which most closely characterized the reported transient. The result of this correlation is shown below:

WOG Transient	Number of Plant No. 7 Transients	Transient $(\text{Reactor-year})^{-1}$
T-1	8	4.38
T-5	24	13.15
T-6	12	6.57
		24.1

Calculation of the frequency of a small break LOCA from a stuck-open PORV is greatly reduced, in the case of plant No. 7, because only three types of initiator transients are involved (T-1, T-5, T-6), because the nodal parameters are the same for these three transients, and also because only a portion of the event tree is affected. As shown in Figure 4, the values of R10 and RVO are calculated as follows:

$$R10 = 5.99 \times 10^{-4}$$
$$RVO = 3.01 \times 10^{-6}$$
$$\text{Small-Break LOCA from a Stuck-Open PORV} = 6.02 \times 10^{-4}$$

Consequently, the frequency for a small-break LOCA from a stuck-open PORV for plant No. 7 using actual PORV operational opening data is 6.02×10^{-4} per reactor-year. It should also be noted that plant No. 7 has a high-head safety injection system (baseline case) and the positioning of PORV block valves need not be considered when dealing with actual PORV openings. Finally, it is also noted that post-TMI hardware changes, which will have the effect of further reducing actual PORV openings at plant No. 7, have not been considered, thereby adding conservatism to the calculations.

In conclusion, the WOG Report satisfactorily models the actual PORV opening data reported in Appendix I of Reference 5 for all 28 plants except

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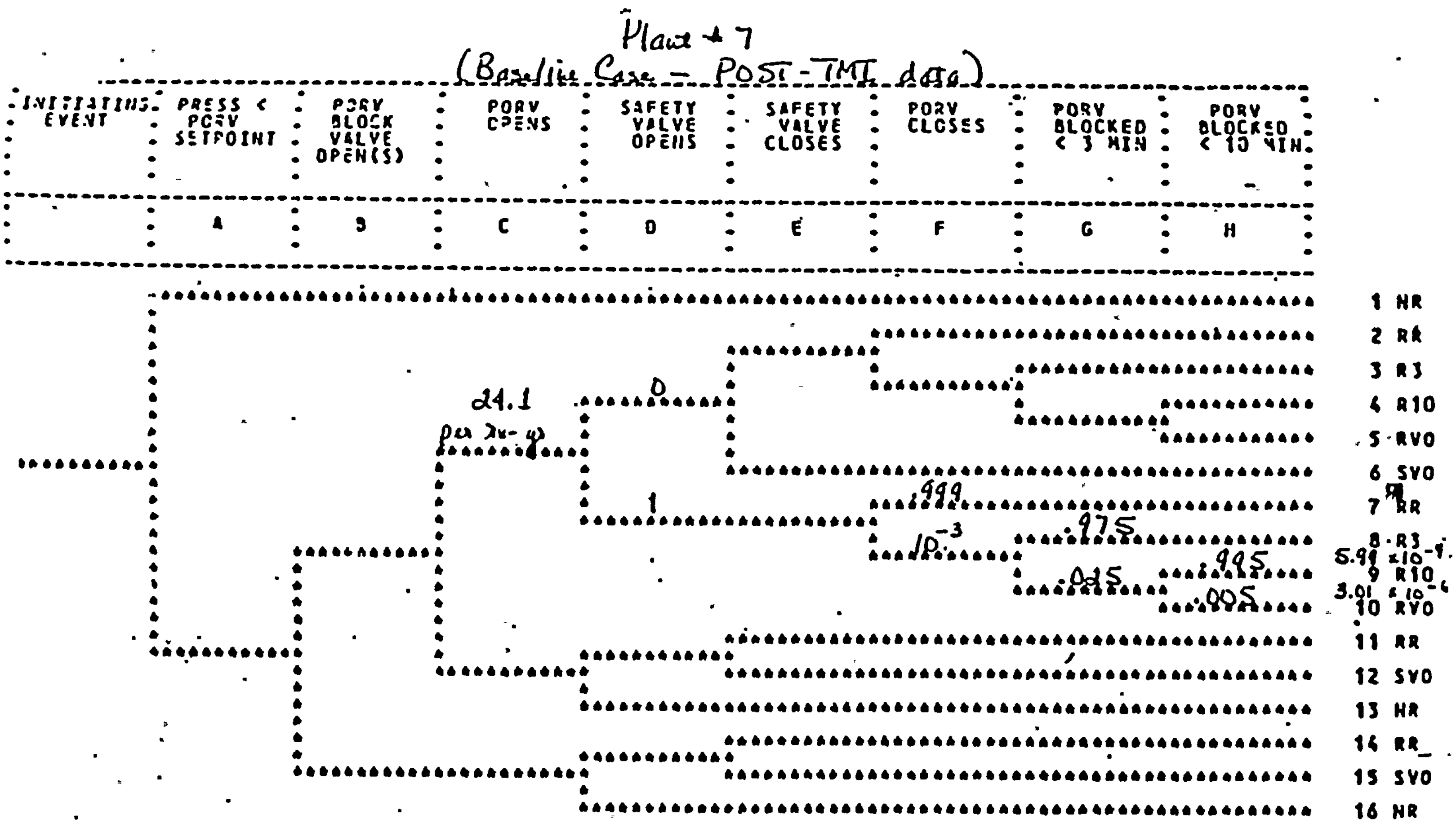

CATEGORY DESCRIPTION
NR NO RELIEF
RR RELIEF+RECLOSE
R3 RELIEF,FAIL OPEN,CLOSE IN 3 MIN
R10 RELIEF,FAIL OPEN,CLOSE IN 10 MIN
RVO RELIEF VALVE FAILS OPEN
SVO SAFETY VALVE FAILS OPEN

Figure 4. Plant No. 7 (Baseline Case - Post TMI Data)

for plant No. 7. In the case of plant No. 7, substitution of actual opening information yields a small-break LOCA frequency of 6.02×10^{-4} per reactor-year, which is below the WASH-1400 median frequency of 1×10^{-3} per reactor-year. This conclusion, of course, assumes that the information of Appendix I to Reference 5 accurately reflects the actual history of the 28 operating plants. Since Reference 5 itself indicates that this information may be incomplete, the data base should be further investigated to ensure that the calculational model of Reference 5 bounds those plants which did not respond to the original Westinghouse survey.

4.2.2 Block Valve Status

The status of PORV block valves at the time of a pressure transient directly effects the probability of a stuck-open PORV or safety valve. WOG investigations revealed that plant practices with regard to the status of PORV block valves vary substantially. On the basis of these data, the baseline case included the assumption that, on the average (i.e., for a generic study), PORVs should be considered to be blocked 55% of the time. Recognizing, however, that varying operating practices will affect the accident frequency predicted for a specific plant, Westinghouse performed a sensitivity study with respect to the status of PORV block valves. The study indicated that the expected PORV stuck-open rate could vary from that predicted in the baseline case by a factor of about 2 for a plant operating with PORVs blocked about 10% of the time. As expected, a variation in the percentage of time a PORV is blocked has an inverse effect on the probability of a small-break LOCA due to a stuck-open safety valve; it increases the frequency from the baseline case by a factor of about 1.5 when the PORVs are blocked 90% of the time and reduces it by a factor of about 3 when the PORVs are blocked 10% of the time.

The above sensitivity studies show that varying block valve status from 10% blocked to 90% blocked has a relatively small impact on the recurrence frequency of a small-break LOCA. For the PORV, there is a factor of approximately 8 between small-break LOCA frequencies when the block valves are open 10% of the time or 90% of the time. For the SRV, there is a factor of approximately 4 between the small-break LOCA frequencies when the block valves

are open 90% of the time or 10% of the time. Further, the bounding calculations of Appendix B (Tables B-5 and B-6) show that there is a factor of 10 between small-break LOCA probabilities for the SRV when block valves are open 100% of the time or are always closed. The same comparison is not meaningful for the PORV case since there is no probability of a PORV LOCA when the block valves are always closed. These comparisons indicate that the WOG report satisfactorily accounts for block valve status and that the report can be considered generally applicable to Westinghouse plants, without regard to block valve status.

4.2.3 PORV Failure Rates

PORV failure rates should be expected to vary between power plants if the operating principles or construction details of plant-specific PORVs differ substantially. As discussed in Section 3.1.2, the WOG study evaluated the probability of a PORV failing to reclose as 10^{-3} per demand on the basis of updating a prior distribution, the WASH-1400 estimate, using domestic Westinghouse plant operating data.

A review of plant-specific PORV installations has revealed that, with very few exceptions, Westinghouse domestic plants are equipped with either Copes Vulcan D-100-160 or Masoneilan 38-20721/20771 model valves. These valve models are substantially similar, each employing an air-loaded, reverse-acting operator. In each case, a large compression spring provides the seating force to the steam and disc (plug). Air loading of a diaphragm overcomes spring pressure to stroke the valve open. Each valve is also designed with a substantial plug guide to ensure plug stability. This feature is provided in the bonnet of the Masoneilan valve and in a cylindrical spool piece (cage) in the Copes Vulcan valve. A preliminary failure modes-and-effects analysis of these two valves does not indicate that their reseat failure rate should differ. Consequently, it is considered that a generic failure rate estimate can provide a plant-specific estimate for Westinghouse plants, except for plants which do not use the Copes Vulcan or Masoneilan models.

With regard to the Westinghouse plant identified as having a PORV different from those of the other Westinghouse plants, the WOG Report made the following statement:

> "As stated in Reference 7, 'The failure of a PORV to reseat fully was recently reported at the McGuire, Unit 1, plant (Duke Power Company is the owner of this facility, which does not yet have an operating license), which was performing hot functional testing. The malfunction was the result of the valve plug binding in the valve bonnet recess area. The PORV installed at the McGuire plant is of a different design than the PORVs installed at all operating Westinghouse-designed plants.' The McGuire PORV is of a design different from the PORV designs used, or planned for use, on Westinghouse NSSS plants; additionally, the McGuire PORV was not procured by Westinghouse for use on the McGuire plant. For these reasons, this occurrence is not considered relevant to this report and has not been factored into the conclusions of this report. With regard to failure rates for preoperational testing, it is not appropriate to factor a preoperational testing failure rate into an overall failure rate, since the intent of preoperational/hot functional testing is to verify proper operation of equipment. Consistent with this, the conclusions presented in this appendix are based on openings and failures which occurred during plant operation."

In view of the above statement, the WOG Report should not be considered to be applicable to McGuire Unit 1 unless it can be shown that the predicted failure rate of 1×10^{-3} is an appropriate estimate of failure for the installed valve.

5. CONCLUSIONS

The conclusions that result from evaluation of the WOG Report against the review criteria of Section 2 are as follows:

- The WOG Report, Reference 5, documents the the post-TMI modifications instituted at Westinghouse-designed NSSS plants which have made a significant reduction in the expected frequency of a small-break LOCA from a stuck-open PORV or safety valve.

- The WOG Report, Reference 5, as supplemented by additional information from Reference 7 makes no attempt to identify a safety-valve failure rate based on historical operating data due to a lack of sufficient data with statistical significance. However, the conservative estimate is used that the safety-valve failure rate is equal to the PORV failure rate where required for the analyses.

- The methods and results of the Licensee's evaluation have been reviewed and the expected frequency of a small-break LOCA from a stuck-open PORV or safety valve is less than the median frequency of 1×10^{-3} per reactor-year of WASH-1400 (2.1×10^{-6} per reactor-year for the PORV and 4.9×10^{-6} per reactor-year for the safety valve, in the baseline case). Furthermore, using the more conservative operator response model and more conservative valve failure data, the expected frequency remains less than the WASH-1400 median probability of 1×10^{-3} per reactor- year (2.5×10^{-4} for the PORV and 9.3×10^{-5} for the safety valve).

- The actual operational data used in the WOG Report and the bases for all assumptions are clearly stated and justified. The source and accuracy of the data have been verified, and the justification of all assumptions follows a logical progression. Some minor discrepancies were discovered in the Westinghouse data (see Appendix B), but these discrepancies did not have a significant impact on the Westinghouse calculations.

- An independent check of the Westinghouse calculations has been performed which verifies the results of the Westinghouse analysis. In addition, further bounding calculations have been performed which show that even with the most conservative assumptions, the probability of a small-break LOCA from a stuck-open PORV or safety valve remains within the WASH-1400 frequency range of a small-break LOCA (9.4×10^{-3} for the PORV and 1.3×10^{-3} for the SRV).

- Additional evolutions not included in the Westinghouse analysis, such as events requiring operator action to open the PORV, over cooling events, and low-temperature, overpressure events, have been considered and found not significant in determining the probability of a small-break LOCA from a stuck-open PORV or SRV.

- The WOG Report is applicable to all Westinghouse plants which have incorporated post-TMI hardware and procedural changes relative to stuck-open PORVs except for McGuire Unit 1, which uses a PORV different than typical Westinghouse plants, subject to the completeness of data in Table I.1 of the WOG Report.

6. REFERENCES

1. "Clarification of TMI Action Plan Requirements".
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NUREG-0737

2. "Generic Evaluation of Feedwater Transients and Small Break Loss-of-Coolant Accidents in Westinghouse-Designed Operating Plants"
NRC Office of Nuclear Reactor Regulation, January 1980
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3. "NRC Action Plan Developed as a Result of the TMI-2 Accident"
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4. R. E. Uhrig (FP&L)*
Letter to D. G. Eisenhut (NRC)
Subject: Turkey Point Units 3 & 4 Post TMI Requirements
March 2, 1981

5. "Probabilistic Analysis and Operational Data in Response to NUREG-0737 Item II.K.3.2 for Westinghouse NSSS Plants"
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6. S. A. Varga (NRC)
Letter to R. E. Uhrig (FP&L)
Subject: Request for Additional Information in Regard to NUREG-0737 Action Item II.K.3.2 for the Turkey Point Plant Units Nos. 3 and 4
February 11, 1982

7. R. E. Uhrig (FP&L)
Letter S. A. Varga (NRC)
Subject: Turkey Points Units 3 and 4 Post-TMI Requirements NUREG-0737 Item II.K.3.2
March 26, 1982

8. J. N. Donohew, Jr. (NRC)
Letter to S. P. Carfagno (FRC)
Subject: Contract No. NRC-03-81-130, Tentative Work Assignment F
July 21, 1981

*This letter is typical of endorsements of the WOG Report by licensees of Westinghouse-designed plants.

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U.S. Nuclear Regulatory Commission, April 1982
NUREG-0909

17. "Data Summaries of Licensee Event Reports on Valves at Commercial Nuclear Power Plants"
NRC Office of Nuclear Regulatory Research, June 1980
NUREG/CR-1363

APPENDIX A

APPENDIX A

EVALUATION OF THE CONTRIBUTION FROM OVERCOOLING EVENTS TO THE TOTAL PROBABILITY OF A SMALL-BREAK LOSS-OF-COOLANT ACCIDENT FROM A STUCK-OPEN POWER OPERATED RELIEF VALVE OR SAFETY VALVE

Purpose

To review the available literature and operational historical data to ascertain whether or not Combustion Engineering and Westinghouse-designed nuclear steam supply system plants need to consider the contribution from overcooling events to the total probability of a small-break LOCA from a stuck-open PORV or safety valve.

Background

Overcooling events can cause a rapid depressurization of the primary system and subsequent initiation of the high pressure safety injection system. To plant operators, a rapid depressurization appears to be very similar to a small-break LOCA. As a consequence of the TMI-2 accident, operator guidelines were instituted to require the PORV blocking valve(s) to be shut, thus terminating a depressurization, if it was caused by a stuck-open PORV. Regardless of the cause of the depressurization, operator action is required to terminate high pressure safety injection upon subsequent repressurization to prevent challanges to safety valves (or PORV if unblocked). The following is a technical evaluation of whether such events can significantly contribute to the number of challenges experienced by the PORV and/or safety valve.

Evaluation

Secondary side overcooling transients usually occur because of overfeeding of a steam generator, demanding too much steam from the steam generators, or introducing excessive amounts of relatively cold auxiliary feedwater into the steam generators. NUREG-0667 [1], "Transient Response of Babcock & Wilcox-Designed Reactors," describes the sensitivity of the once-through steam generator (OSTG) in B&W designs to such overcooling transients. Specifically, it was concluded that:

"Because the heat removed is proportional to the transfer area, the amount of heat removed by an OTSG is essentially directly proportional to the height of liquid on the secondary side. As such, any change in secondary coolant level directly affects the amount of heat capable of being removed. This, coupled with the relatively smaller secondary side liquid inventory, results in a fairly rapid primary system response to secondary coolant system perturbations."

Reference 1 also describes the sensitivity of a U-tube steam generator, such as the kind presently used in Westinghouse and Combustion Engineering plants. It was concluded that:

"Since the heat removal rate is proportional to the product of the heat transfer coefficient, heat transfer area, and temperature difference, and because the product of the heat transfer area and heat transfer coefficient is usually high, only small changes in primary to secondary temperature difference are needed to accommodate rather large changes in heat removal rate. Because of this and because the volume of water on the secondary side surrounding the U-tubes is large, perturbations on the secondary side of the inverted U-tube steam generator, such as feedwater from changes or system pressure changes, do not readily affect the behavior of the primary coolant system."

Based upon both of these descriptions, it can be concluded that Babcock & Wilcox designed reactors are more susceptible to depressurizations caused by overcooling transients than reactors designed by Westinghouse or Combustion Engineering. This conclusion is supported by historical operational data. A Babcock & Wilcox generic report [2], "Report on Power-Operated Relief Valve Opening Probability and Justification for Present System and Setpoints," states that 8 overcooling transients have initiated high pressure safety injection system flow in 392 reactor trips, and that the current frequency of reactor trips is six trips per reactor-year per plant. Thus, for Babcock & Wilcox-designed reactors, the frequency of overcooling events with subsequent high pressure safety injection system flow equals 0.122 events per reactor-year. For plants designed either by Westinghouse or Combustion Engineering, very little pre-TMI information is readily available concerning plant response to events that overcooled the primary system in excess of the normal cooling expected following a reactor trip. Reference 1 states, "Since TMI-2, three events that depressurized the primary system to the HPI actuation setpoint have occurred in plants with reactors designed by Westinghouse and Combustion Engineering." Two of these events involved stuck-open turbine

bypass valves, and one was the result of a steam generator tube rupture. Since the steam generator tube rupture is a separate initiating event, it can be excluded from this study. During the 2 years between the TMI-2 accident and the completion of Reference 1, 41.7 reactor operating years were recorded by Westinghouse and Combustion Engineering plants. Therefore, the frequency of overcooling events with subsequent high pressure safety injection system flow equals 4.8×10^{-2} events per reactor-year for Westinghouse and Combustion Engineering plants.

To quantify the probability that an overcooling event will lead to a small-break LOCA from a stuck-open PORV or safety valve, an event tree was constructed. This event tree is shown in Figure A-1. The following paragraphs describe the branch nodes which are used in the construction of the event tree. Paths branching upward at these nodes represent a "yes" response to the question, while those paths branching downward represent a "no" response. When quantifying the event tree, the probabilities shown in Table A-1 the probabilities represent the probability that the answer to the question is yes or no, rather than the availability and unavailability of a system.

Node A

Operator stops HPI prior to PORV setpoint pressure

Upward paths at this node indicate that the operator has throttled or secured the high pressure safety injection system prior to the reactor coolant system pressure reaching the PORV opening setpoint pressure. The recommended PORV opening setpoint pressure is 2350 psia on Westinghouse-designed plants.

Downward paths at this node indicate that the operator has failed to throttle or secure the high pressure safety injection prior to the reactor coolant system pressure reaching the PORV opening setpoint pressure.

Node B

PORV block valve(s) open

Upward paths at this node indicate that at least one PORV block valve is open when the challenge to the PORV occurs. This applies both to the case

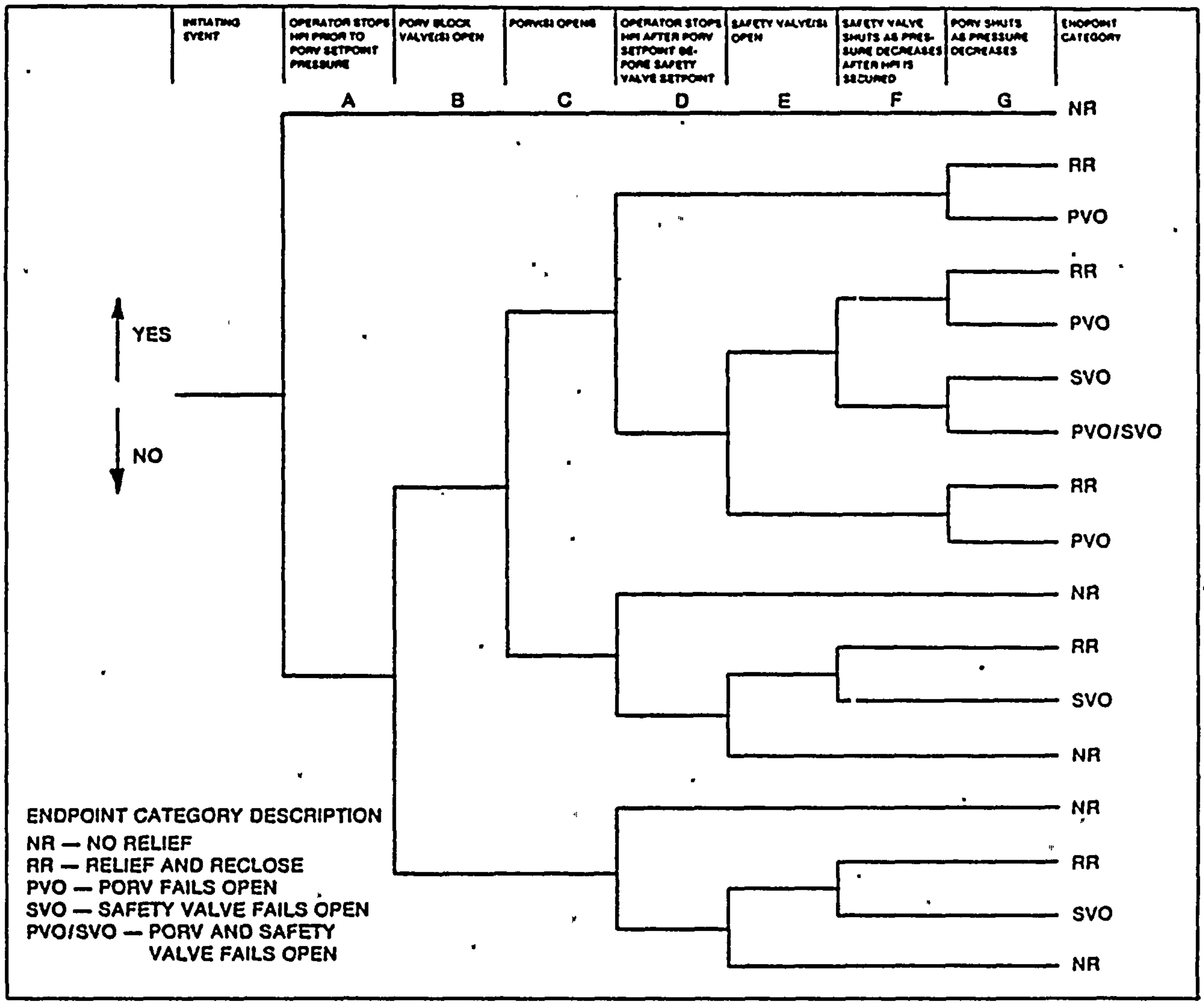

Figure A-1. Overcooling Event Transient Event Tree

Node B (Cont.)

where the PORV block valve is manually positioned, and the case of automatic open/closure systems where the block valve may be automatically moved.

Downward paths at this node represent those events where all the PORV block valves are closed when the PORV opening setpoint pressure is reached.

This node is not considered to be relevant for those events where the PORV opening setpoint pressure is not reached.

Node C

PORV(s) open

Upward paths at this node represent the PORV(s) opening after the PORV opening setpoint pressure is reached.

Downward paths at this node represent the PORV(s) staying closed after the PORV opening setpoint pressure is reached.

Since this node is relevant only for those events where the PORV opening setpoint pressure is reached and the PORV block valves(s) are open, the probability of the PORV staying closed represents the failure of the PORV to open on demand. This probability for the failure of the PORV to open on demand must therefore include such failures as pressure sensors, pressure transmitters, and control channels, as well as those failures associated directly with the PORV.

(Note: This analysis assumes that the PORV setpoint is exceeded one time per event, resulting in one PORV opening. Multiple PORV cycles are not considered for the following reasons:

1. The results of this analysis are to be compared to the WOG report. The WOG report considers one PORV opening per initiator event.

Node C (Cont.)

2. The operator who fails to secure HPI prior to the first PORV opening would be alerted to the need to secure HPI prior to a second opening.

The question of multiple cycling of multiple PORVs is addressed in the bounding calculations of Appendix B to this report.)

Node D

Operator stops HPI after PORV setpoint before safety valve setpoint

Upward paths at this node indicate that the operator has throttled or terminated HPI after the PORV opening setpoint pressure has been exceeded but before the safety valve opening setpoint pressure is reached. The recommended opening setpoint for safety valves on Westinghouse-designed plants is 2500 psia.

Downward paths at this node indicate that the operator has failed to throttle or terminate the HPI before the safety valve opening setpoint pressure was reached.

The probability at this node must reflect whether the PORV and the PORV block valve are open, since the probability of reaching the safety valve opening setpoint pressure is significantly reduced if the PORV and PORV block valve are open.

Node E

Safety valve(s) open

Upward paths at this node represent the opening of a safety valve at the safety valve opening setpoint pressure.

Downward paths at this node represent the safety valve staying closed after the safety valve opening setpoint pressure is reached.

This node is not considered to be relevant for those events where the safety valve opening setpoint pressure is not reached.

Node F

Safety valves(s) shut as pressure decreases after HPI is secured

Upward paths at this node represent the successful reclosing of the safety valves(s) when the reactor coolant system pressure decreases below the

Node F (Cont.)

safety valve opening pressure setpoint after the HPI system is secured.

Downward paths at this node represent the failure of the safety valve(s) to reclose when the reactor coolant system pressure decreases below the safety valve opening pressure setpoint after the HPI system is secured.

Intuitively inherent in the probability assigned at this node is the fact that, at some point in the overcooling event, the HPI system will be secured allowing the reactor coolant system pressure to decrease below the safety valve opening setpoint pressure.

Node G

PORV(s) shuts as pressure decreases

Upward paths at this node indicate the successful reclosing of the PORV(s) when the reactor coolant system pressure decreases below the PORV opening pressure setpoint after the HPI system is secured.

Downward paths at this node indicate the failure of the PORV(s) to reclose when the reactor coolant system pressure decreases below the PORV opening pressure setpoint after the HPI system is secured.

As with the probability assigned to Node F, the probability assigned to Node G assumes that at some point in the overcooling event, the HPI system will be secured allowing the reactor coolant system pressure to decrease below the PORV opening setpoint pressure.

Each endpoint path is categorized by a consequence description as defined below:

NR - No PORV or safety valve relief occurs

RR - Relief occurs but the valve(s) recloses on demand

PVO - PORV(s) opens and fails to reclose

SVO - Safety valve(s) opens and fails to reclose

PVO/SVO - PORV(s) and safety valve(s) opens and fails to reclose.

In order to quantify the event tree paths, probability data are needed for each path at each node of the event tree. The probability data represent the answer to the question at that node. The probabilities and the reference source for the probability used for each node are given in Table A-1.

The results of the various endpoint paths are shown on Table A-2. The expected frequencies of a small-break LOCA from a stuck-open PORV or safety valve from an overcooling initiated transient event are 6.1×10^{-6} per reactor-year and 6.9×10^{-6} per reactor year, respectively. From this, it can be concluded that overcooling events are not a significant contributor to the expected frequency of a small-break LOCA from a stuck-open PORV or safety valve for Westinghouse and Combustion Engineering-designed NSSS plants.

Table A-1. Probabilities Assigned to Overcooling Event Tree Nodes

Node	Node Description	Probability Assigned	Discussion	References
-	Initating transient event frequency	0.048/ reactor-year	Frequency was determined from events reported in Reference 1 and total Westinghouse and Combustion Engineering plant operating time from 4/1/78-4/1/80	1,3,4,5
A	Operator stops HPI prior to PORV set-point pressure	0.985	Probability was determined from Reference 6 for an operator with a moderate to high stress level	6
B	PORV block valves(s) open	0.45	Probability was based on a summary of historical operating data for Westinghouse plants as reported in Reference 7	7
C	PORV(s) open	0.99	Conservative engineering judgment coupled with information from Reference 8 for a single channel non-redundant control system	8
D	Operator stops HPI after PORV set-point before safety valve setpoint	0.999 or 0.1	Note that two probabilities are assigned to this node. The first probability, 0.999, is for the case where the PORV(s) and block valve(s) are open, making it highly unlikely that the safety valve opening setpoint pressure would ever be reached. The second probability, 0.1, is for the case where the PORV(s) or block valve(s) do not or are not open. Both	8,9

Table A-1 (Cont.)

Node	Node Description	Probability Assigned	Discussion	References
D Cont.			probabilities are based on plant and system characteristics from Reference 9 and general human error rate estimates from Reference 8.	
E	Safety valve(s) opens	0.99997	Probability was based on information from Reference 8, Volume V, Page V-38.	8
F	HPI secured, safety valve shuts as pressure descrease	0.981	Probabilty is based on a conservative engineering judgment using information from References 7 and 8 (see Section 3.2.6 of this report for more detailed discussion.)	7,8
G	PORV(s) shuts as pressure decreases	0.981	See discussion of Node F above for information.	7,8

Table A-2. Endpoint Category Description and Frequencies

Endpoint Category	Description	Frequency per Reactor-Year
NR	No PORV or safety valve relief occurs	4.7×10^{-2}
RR	Relief occurs but the valve(s) recloses on demand	6.6×10^{-4}
PVO	PORV(s) opens and fails to reclose	6.1×10^{-6}
SVO	Safety valve(s) opens and fails to reclose	6.9×10^{-6}
PVO/SVO	PORV(s) and safety valve(s) open and fail to reclose	1.2×10^{-10}

REFERENCES

1. "Transient Response of Babcock & Wilcox-Designed Reactors"
   NRC Office of Nuclear Reactor Regulation, May 1980
   NUREG-0667

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   Babcock & Wilcox, Nuclear Power Generation Division, April 1981
   Document No. 12-11227792

3. "Nuclear Power Plant Operating Experience-1978, Annual Report"
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4. "Nuclear Power Plant Operating Experience-1979, Annual Report"
   NRC Office of Management and Program Analysis, May 1981
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   NRC Office of Management and Program Analysis, June 19, 1980
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6. "Handbook of Human Reliability Analysis With Emphasis on Nuclear Power Plant Applications"
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7. "Probabilistic Analysis and Operational Data in Response to NUREG-0737, Item II.K.3.2 for Westinghouse NSSS Plants"
   Westinghouse Electric Corporation, February 1981
   WCAP-9804

8. "Reactor Safety Study, An Assessment of Accident Risks in U.S. Commercial Nuclear Power Plants"
   U.S. Nuclear Regulatory Commission, October 1975
   WASH-1400 (NUREG-75/014)

9. "Generic Evaluation of Feedwater Transients and Small Break Loss-of-Coolant Accidents in Westinghouse-Designed Operating Plants"
   NRC Office of Nuclear Reactor Regulation, January 1980
   NUREG-0611

APPENDIX B

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APPENDIX B

VERIFICATION OF CALCULATIONS

Purpose

To perform an independent check of the Westinghouse calculations in order to verify the Westinghouse results and also to perform additional calculations in order to arrive at bounding values for a small-break LOCA from a stuck-open PORV and SRV.

Background

In Reference 5, Westinghouse presents the event trees used to calculate the probabilities for 16 different transients, the input data applied for each transient, and the results of application of the data to the event trees. This appendix presents the results of an independent check of the Westinghouse calculations using the D-BASE capabilities of an Xerox-860 System. Further, by modifying some of the input data appropriately, additional calculations were performed to derive bounding values for the case of a small-break LOCA from a stuck-open PORV and also for a stuck-open SRV. The bounding values were derived by simultaneously considering multiple cycles of multiple PORVs, the conservative operator response model, and conservative initial block-valve positions.

Evaluation

1. Pre-TMI Data

The results of an independent check of Westinghouse calculations, using the pre-TMI baseline input data shown in Table 2 (page 32) of this report and the event trees shown in Figures 1 and 2 (pages 11 and 12) of this report, are given in Table B-1. These results compare to the Westinghouse results of Reference 5 as follows:

	Pre-TMI Baseline Case					
	NR	RR	R3	R10	RVO	SVO
Original W Results of Ref. 5	5.5	0.12	1.0×10^{-4}	8.9×10^{-6}	5.1×10^{-7}	9.6×10^{-6}
Table B-1	5.5	0.07	6.3×10^{-5}	3.7×10^{-6}	1.1×10^{-7}	3.0×10^{-6}

In reviewing Reference 5, it was noted that the input data shown in Table 3.4 of Reference 5 (reproduced in Table 2, page 32, of this report) were inconsistent with the written descriptions of the various input events of Reference 5 as follows:

	Table 3.4	Written Description
Event T-4 Node P(A)	0.02	0.001
Event T-4, Node P(D: B or C)	0.01	0.001
Event T-5, Node P(A)	0.01	0.1
Event T-13, Node P(D: B and C)	0.001	0.01
Event T-16, Node P(G)	0.01	0.05

Making the above changes in input data, the calculations were rerun. The results are given in Table B-2.

Also, it was noted that Westinghouse apparently used some slight variations in the event initiation frequencies when doing its calculations. These changes can be seen by reviewing the total probabilities (right-hand column) for each of the 10 events are shown in Table 3.5 of Reference 5. These modifications are identified as follows:

Event	Event Frequencies (Reactor-yr)$^{-1}$ Table 3.4	Table 3.5
T-2	0.27	0.2
T-6	0.07	0.1
T-7A	0.01	0.05
T-8	1×10^{-4}	2×10^{-3}
T-9A	1×10^{-4}	2×10^{-3}
T-16	0.03	0.06

Using both the modified node probabilities and the modified event frequencies shown above, the calculations were rerun. The results are given in Table B-3. A comparison of the Westinghouse results and the results of Tables B-2 and B-3 are presented below:

	Pre-TMI Baseline Case					
	NR	RR	R3	R10	RVO	SVO
Original W Results of Ref. 5 (as given in Table 3.5)	5.5	0.12	1.0×10^{-4}	8.9×10^{-6}	5.1×10^{-7}	9.6×10^{-6}
Table B-2 (node probabilities modified according to the written descriptions)	5.5	0.11	9.1×10^{-5}	5.6×10^{-6}	1.3×10^{-7}	8.3×10^{-6}
Table B-3 (node probabilities and event frequencies modified according to the written descriptions and Table 3.5)	5.5	0.12	1.0×10^{-4}	9.4×10^{-6}	5.1×10^{-7}	9.6×10^{-6}

As can be seen, the results of Table B-3 are in close agreement with the original Westinghouse calculations. In addition, since these results are more conservative than those of Tables B-1 and B-2, modified node and event probabilities were used in calculating post-TMI results.

2. Post-TMI Data

The input data were then converted for the post-TMI baseline case as shown in Table 3 of this report. Calculations were repeated with the results presented in Table B-4. A comparison with the post-TMI baseline case given by Westinghouse in Reference 5 follows:

	Post-TMI Baseline Case					
	NR	RR	R3	R10	RVO	SVO
W Results of Ref. 5	5.5	0.05	4.4×10^{-5}	2.0×10^{-6}	6.5×10^{-8}	4.9×10^{-6}
Table B-4	5.5	0.06	5.7×10^{-5}	2.5×10^{-6}	6.3×10^{-8}	4.8×10^{-6}

Again, these results closely parallel the Westinghouse results and provide an independent verification of the Westinghouse calculations.

Summarizing the results of these check calculations, the following table shows a comparison of the frequencies of a small-break LOCA from a stuck-open PORV and SRV for the pre-TMI and post-TMI baseline (high-head plant) cases:

	Westinghouse (Reference 5)	Check-Calculation of This TER
Small-break LOCA from Stuck-open PORV	9.4×10^{-6}	9.9×10^{-6}
Small-break LOCA from Stuck-open SRV	9.6×10^{-6}	9.6×10^{-6}

	Westinghouse (Reference 5)	Check-Calculation of This TER
Small-break LOCA from Stuck-open PORV	2.1×10^{-6}	2.6×10^{-6}
Small-break LOCA from Stuck-open SRV	4.9×10^{-6}	4.8×10^{-6}

Bounding Values

In order to convert the post-TMI baseline figures to a bounding case, changes were made to (1) provide for the most conservative initial block-valve

position (100% open for PORV LOCA, 100% closed for SRV LOCA), (2) provide for the conservative operator model, (3) to include the conservative PORV/SRV failure rate of 1.1×10^{-2} per demand as discussed in Section 3.2.4, and (4) account for multiple cycles of multiple PORVs and SRVs. To account for multiple cycles of multiple valves, all results (except event T-15, spurious PORV opening) were multiplied by the factor 15 (5 cycles of each of 3 valves - see Section 3.2.5 of this report).

In addition to the above modifications to the input data for the bounding calculations, further changes were made in the case of Event T-15. Event T-15 was not multiplied by the factor of 15 because multiple cycles of multiple valves are not applicable to the case of inadvertent opening of the PORV. At the same time, however, the PORV failure rate of 10^{-3} per demand used by Westinghouse was increased to one failure per demand for the bounding case. This is because when the PORV inadvertently or spuriously opened, it is most conservative to assume that the valve has failed in the open position and will not close. The actual input data and results of the T-15 calculations for the PORV bounding case are listed below:

Initiator Frequency	P(B)	$P(\overline{E})$	$P(\overline{G})$	$P(\overline{H})$
0.002	1.0	1.0	0.4	0.05

NR	RR	R3	R10	RVO
0	0	1.2×10^{-3}	7.6×10^{-4}	4×10^{-5}

The results of the bounding value calculations are given in Table B-5 (PORV) and Table B-6 (SRV) and are summarized below:

	Bounding Values
Post-TMI Small-Break LOCA from Stuck-Open PORV (From Table B-5)	9.4×10^{-3} per reactor-yr
Post-TMI Small-Break LOCA from Stuck-Open SRV (From Table B-6)	1.3×10^{-3} per reactor-yr

These bounding calculations show that even with the extremely conservative assumptions of block valves open 100% of the time (for the PORVs) or shut 100% of the time (for the SRVs), conservative operator model, increased failure rate, 15 multiple cycles per initiator event (other than event T-15), and no probability of closure following a spurious opening, the frequency of small-break LOCA from a stuck-open PORV or SRV remains within the range of frequencies for a small-break LOCA of WASH-1400 (10^{-2} to 10^{-4} per reactor-year).

Table B-1: Pre-TMI Baseline, Original Node Prob & Event Freq

Event	Freq	A	B	C	D1	D2	E	F	G	H
T1:Loss MF	3.000000000	0.980000000	0.450000000	0.990000000	0.010000000	0.001000000	0.999000000	0.999000000	0.950000000	0.990000000
T2:1 OS AC	0.270000000	0.980000000	0.450000000	0.990000000	0.010000000	0.001000000	0.999000000	0.999000000	0.950000000	0.990000000
T3:1 NO AC	0.000007000	0.980000000	0.450000000	0.990000000	0.010000000	0.001000000	0.999000000	0.999000000	0.950000000	0.990000000
T4:T TRIP	1.000000000	0.980000000	0.450000000	0.990000000	0.010000000	0.001000000	0.999000000	0.999000000	0.950000000	0.990000000
T5:LD REJ	1.000000000	0.990000000	0.450000000	0.990000000	0.100000000	0.010000000	0.999000000	0.999000000	0.950000000	0.990000000
T6:MSIV cl	0.070000000	0.800000000	0.450000000	0.990000000	0.200000000	0.020000000	0.999000000	0.999000000	0.950000000	0.990000000
T7A:In SI	0.010000000	0.750000000	0.450000000	0.990000000	0.100000000	0.001000000	0.999000000	0.999000000	0.200000000	0.900000000
T8:MF Rupt	0.000100000	0.990000000	0.450000000	0.990000000	0.010000000	0.001000000	0.999000000	0.999000000	0.200000000	0.900000000
T9A:MS Rup	0.000100000	0.750000000	0.450000000	0.990000000	0.100000000	0.001000000	0.999000000	0.999000000	0.200000000	0.900000000
T10:CVCS	0.030000000	0.999000000	0.450000000	0.990000000	0.001000000	0.001000000	0.999000000	0.999000000	0.950000000	0.990000000

Event	NR=	RR=	R3=	R10=	RVO=	SVO=
T1:Loss MF	2.972937300	0.027035610	0.000025393	0.000001323	0.000000013	0.000000359
T2:1 OS AC	0.267564357	0.002433204	0.000002285	0.000000119	0.000000001	0.000000032
T3:1 NO AC	0.000006936	0.000000063	0.000000000	0.000000000	0.000000000	0.000000000
T4:T TRIP	0.990979100	0.009011870	0.000008464	0.000000441	0.000000004	0.000000119
T5:LD REJ	0.994990500	0.005004445	0.000004232	0.000000220	0.000000002	0.000000599
T6:MSIV cl	0.062210400	0.007781685	0.000005925	0.000000308	0.000000003	0.000001677
T7A:In SI	0.008747625	0.001251121	0.000000222	0.000000801	0.000000089	0.000000139
T8:MF Rupt	0.000099548	0.000000450	0.000000000	0.000000000	0.000000000	0.000000000
T9A:MS Rup	0.000087476	0.000012511	0.000000002	0.000000008	0.000000000	0.000000001
T10:CVCS	0.029986618	0.000013368	0.000000012	0.000000000	0.000000000	0.000000000

T11:RC Flw	A	B	C	D1	D2	E	F	G	H
0.120000000	0.990000000	0.450000000	0.990000000	0.001000000	0.001000000	0.999000000	0.999000000	0.950000000	0.990000000

NR=	0.119464734	RR=	0.000534729	R3=	0.000000507	R10=	0.000000026	RVO=	0.000000000	SVO=	0.000000001

T12:T11 AL	A	B	C	D1	D2	E	F	G	H
0.010000000	0.950000000	0.450000000	0.990000000	0.010000000	0.001000000	0.999000000	0.999000000	0.950000000	0.990000000

NR=	0.009774477	RR=	0.000225296	R3=	0.000000211	R10=	0.000000011	RVO=	0.000000000	SVO=	0.000000002

T13:	A	B	C	D1	D2	E	F	G	H
0.001000000	0.500000000	0.450000000	0.990000000	0.200000000	0.001000000	0.999000000	0.999000000	0.950000000	0.990000000

NR=	0.000721800	RR=	0.000277921	R3=	0.000000211	R10=	0.000000011	RVO=	0.000000000	SVO=	0.000000055

T14:Bank	A	B	C	D1	D2	E	F	G	H
0.010000000	0.990000000	0.450000000	0.990000000	0.001000000	0.001000000	0.999000000	0.999000000	0.950000000	0.990000000

NR=	0.009955394	RR=	0.000044560	R3=	0.000000042	R10=	0.000000002	RVO=	0.000000000	SVO=	0.000000000

T16:SG Tub	A	B	C	D1	D2	E	F	G	H
0.030000000	0.500000000	0.450000000	0.990000000	0.000000000	0.000000000	1.000000000	0.999000000	0.990000000	0.990000000

NR=	0.023317500	RR=	0.006675817	R3=	0.000006615	R10=	0.000000068	RVO=	0.000000000	SVO=	0.000000000

TOTALS

NR=	5.490843765	RR=	0.060302650	R3=	0.000054121	R10=	0.000003338	RVO=	0.000000112	SVO=	0.000002984

SUMMARY OF RESULTS

	NR	RR	R3	R10	RVO	SVO
Table B-1 TOTALS	5.5	.06	5.4 E-5	3.3 E-6	1.1 E-7	3.0 E-6
Event T-15	.01	.009	8.6 E-6	4.5 E-7	4.5 E-9	-------
GRAND TOTAL	5.5	.07	6.3 E-5	3.7 E-6	1.1 E-7	3.0 E-6

Table B-2: Pre-TMI Baseline, Node Prob Modified

Sequence	Frequency	A	B	C	D1	D2	E	F	G	H
T1:Loss MF	3.000000000	0.980000000	0.450000000	0.990000000	0.010000000	0.001000000	0.999000000	0.999000000	0.950000000	0.990000000
T2:1 OS AC	0.270000000	0.980000000	0.450000000	0.990000000	0.010000000	0.001000000	0.999000000	0.999000000	0.950000000	0.990000000
T3:1 NO AC	0.000007000	0.980000000	0.450000000	0.990000000	0.010000000	0.001000000	0.999000000	0.999000000	0.950000000	0.990000000
T4:T TRIP	1.000000000	0.999000000	0.450000000	0.990000000	0.001000000	0.001000000	0.999000000	0.999000000	0.950000000	0.990000000
T5:LD REJ	1.000000000	0.900000000	0.450000000	0.990000000	0.100000000	0.010000000	0.999000000	0.999000000	0.950000000	0.990000000
T6:MSIV cl	0.070000000	0.800000000	0.450000000	0.990000000	0.200000000	0.020000000	0.999000000	0.999000000	0.950000000	0.990000000
T7A:In SI	0.010000000	0.750000000	0.450000000	0.990000000	0.100000000	0.001000000	0.999000000	0.999000000	0.200000000	0.900000000
T8:MF Rupt	0.000100000	0.990000000	0.450000000	0.990000000	0.010000000	0.001000000	0.999000000	0.999000000	0.200000000	0.900000000
T9A:MS Rup	0.000100000	0.750000000	0.450000000	0.990000000	0.100000000	0.001000000	0.999000000	0.999000000	0.200000000	0.900000000
T10:CVCS	0.030000000	0.999000000	0.450000000	0.990000000	0.001000000	0.001000000	0.999000000	0.999000000	0.950000000	0.990000000

Sequence	NR=	RR=	R3=	R10=	RVO=	SVO=
T1:Loss MF	2.972937300	0.027035610	0.000025393	0.000001323	0.000000013	0.000000359
T2:1 OS AC	0.267564357	0.002433204	0.000002285	0.000000119	0.000000001	0.000000032
T3:1 NO AC	0.000006936	0.000000063	0.000000000	0.000000000	0.000000000	0.000000000
T4:T TRIP	0.999553945	0.000445608	0.000000423	0.000000022	0.000000000	0.000000001
T5:LD REJ	0.949905000	0.050044459	0.000042322	0.000002205	0.000000022	0.000005990
T6:MSIV cl	0.062210400	0.007781685	0.000005925	0.000000308	0.000000003	0.000001677
T7A:In SI	0.008747625	0.001251121	0.000000222	0.000000801	0.000000089	0.000000139
T8:MF Rupt	0.000099548	0.000000450	0.000000000	0.000000000	0.000000000	0.000000000
T9A:MS Rup	0.000087476	0.000012511	0.000000002	0.000000008	0.000000000	0.000000001
T10:CVCS	0.029986618	0.000013368	0.000000012	0.000000000	0.000000000	0.000000000

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Event	Initiator	A	B	C	D1	D2	E	F	G	H
T11:RC Flw	0.120000000	0.990000000	0.450000000	0.990000000	0.001000000	0.001000000	0.999000000	0.999000000	0.950000000	0.990000000
T12:T11 AL	0.010000000	0.950000000	0.450000000	0.990000000	0.010000000	0.001000000	0.999000000	0.999000000	0.950000000	0.990000000
T13:RCP	0.001000000	0.500000000	0.450000000	0.990000000	0.200000000	0.010000000	0.999000000	0.999000000	0.950000000	0.990000000
T14:Bank	0.010000000	0.990000000	0.450000000	0.990000000	0.001000000	0.001000000	0.999000000	0.999000000	0.950000000	0.990000000
T16:SG Tub	0.030000000	0.500000000	0.450000000	0.990000000	0.000000000	0.000000000	1.000000000	0.999000000	0.950000000	0.990000000

Event	NR=	RR=	R3=	R10=	RVO=	SVO=
T11:RC Flw	0.119464734	0.000534729	0.000000507	0.000000026	0.000000000	0.000000001
T12:T11 AL	0.009774477	0.000225296	0.000000211	0.000000011	0.000000000	0.000000002
T13:RCP	0.000721800	0.000277919	0.000000211	0.000000011	0.000000000	0.000000057
T14:Bank	0.009955394	0.000044560	0.000000042	0.000000002	0.000000000	0.000000000
T16:SG Tub	0.023317500	0.006675817	0.000006348	0.000000330	0.000000003	0.000000000
TOTALS	5.454333110	0.096776400	0.000083903	0.000005166	0.000000131	0.000008259

SUMMARY OF RESULTS

	NR	RR	R3	R10	RVO	SVO
Table B-2 TOTALS	5.5	.1	8.4 E-5	5.2 E-6	1.3 E-7	8.3 E-6
Event T-15	.01	.009	8.6 E-6	4.5 E-7	4.5 E-9	
GRAND TOTAL	5.5	.11	9.1 E-5	5.6 E-6	1.3 E-7	8.3 E-6

Table B-3: Pre-TMI Baseline, Node Prob & Event Freq Modified

T1:Loss MF	A	B	C	D1	D2	E	F	G	H
3.000000000	0.986000000	0.450000000	0.990000000	0.010000000	0.001000000	0.999000000	0.999000000	0.950000000	0.990000000

NR=	2.972937300	RR=	0.027035610	R3=	0.000025393	R10=	0.000001323	RVO=	0.000000013	SVO=	0.000000359

T2:1 OS AC	A	B	C	D1	D2	E	F	G	H
0.200000000	0.980000000	0.450000000	0.990000000	0.010000000	0.001000000	0.999000000	0.999000000	0.950000000	0.990000000

NR=	0.198195820	RR=	0.001802374	R3=	0.000001692	R10=	0.000000088	RVO=	0.000000000	SVO=	0.000000023

T3:1 NO AC	A	B	C	D1	D2	E	F	G	H
0.000007000	0.980000000	0.450000000	0.990000000	0.010000000	0.001000000	0.999000000	0.999000000	0.950000000	0.990000000

NR=	0.000006936	RR=	0.000000063	R3=	0.000000000	R10=	0.000000000	RVO=	0.000000000	SVO=	0.000000000

T4:T TRIP	A	B	C	D1	D2	E	F	G	H
1.000000000	0.999000000	0.450000000	0.990000000	0.001000000	0.001000000	0.999000000	0.999000000	0.950000000	0.990000000

NR=	0.999553945	RR=	0.000445608	R3=	0.000000423	R10=	0.000000022	RVO=	0.000000000	SVO=	0.000000001

T5:LD REJ	A	B	C	D1	D2	E	F	G	H
1.000000000	0.900000000	0.450000000	0.990000000	0.100000000	0.010000000	0.999000000	0.999000000	0.950000000	0.990000000

NR=	0.949905000	RR=	0.050044459	R3=	0.000042322	R10=	0.000002205	RVO=	0.000000022	SVO=	0.000005990

T6:MSIV cl	A	B	C	D1	D2	E	F	G	H
0.100000000	0.800000000	0.450000000	0.990000000	0.200000000	0.020000000	0.999000000	0.999000000	0.950000000	0.990000000

NR=	0.088872000	RR=	0.011116693	R3=	0.000008464	R10=	0.000000441	RVO=	0.000000004	SVO=	0.000002396

T7A:In SI	A	B	C	D1	D2	E	F	G	H
0.050000000	0.750000000	0.450000000	0.990000000	0.100000000	0.001000000	0.999000000	0.999000000	0.200000000	0.900000000

NR=	0.043738125	RR=	0.006255607	R3=	0.000001113	R10=	0.000004009	RVO=	0.000000445	SVO=	0.000000698

T8:MF Rupt	A	B	C	D1	D2	E	F	G	H
0.002000000	0.990000000	0.450000000	0.990000000	0.010000000	0.001000000	0.999000000	0.999000000	0.200000000	0.900000000

NR=	0.001990979	RR=	0.000009011	R3=	0.000000001	R10=	0.000000006	RVO=	0.000000000	SVO=	0.000000000

T9A:MS Rup	A	B	C	D1	D2	E	F	G	H
0.002000000	0.750000000	0.450000000	0.990000000	0.100000000	0.001000000	0.999000000	0.999000000	0.200000000	0.900000000

NR=	0.001749525	RR=	0.000250224	R3=	0.000000044	R10=	0.000000160	RVO=	0.000000017	SVO=	0.000000027

T10:CVCS	A	B	C	D1	D2	E	F	G	H
0.030000000	0.999000000	0.450000000	0.990000000	0.001000000	0.001000000	0.999000000	0.999000000	0.950000000	0.990000000

NR=	0.029986618	RR=	0.000013368	R3=	0.000000012	R10=	0.000000000	RVO=	0.000000000	SVO=	0.000000000

T11:RC Flw	A	B	C	D1	D2	E	F	G	H
0.120000000	0.990000000	0.450000000	0.990000000	0.001000000	0.001000000	0.999000000	0.999000000	0.950000000	0.990000000

NR=	0.119464734	RR=	0.000534729	R3=	0.000000507	R10=	0.000000026	RVO=	0.000000000	SVO=	0.000000001

T12:T11 AL	A	B	C	D1	D2	E	F	G	H
0.010000000	0.950000000	0.450000000	0.990000000	0.010000000	0.001000000	0.999000000	0.999000000	0.950000000	0.990000000

NR=	0.009774477	RR=	0.000225296	R3=	0.000000211	R10=	0.000000011	RVO=	0.000000000	SVO=	0.000000002

T13:RCP	A	B	C	D1	D2	E	F	G	H
0.001000000	0.500000000	0.450000000	0.990000000	0.200000000	0.010000000	0.999000000	0.999000000	0.950000000	0.990000000

NR=	0.000721800	RR=	0.000277919	R3=	0.000000211	R10=	0.000000011	RVO=	0.000000000	SVO=	0.000000057

T14:Bank	A	B	C	D1	D2	E	F	G	H
0.010000000	0.990000000	0.450000000	0.990000000	0.001000000	0.001000000	0.999000000	0.999000000	0.950000000	0.990000000

NR=	0.009955394	RR=	0.000044560	R3=	0.000000042	R10=	0.000000002	RVO=	0.000000000	SVO=	0.000000000

T16:SG Tub	A	B	C	D1	D2	E	F	G	H
0.060000000	0.500000000	0.450000000	0.990000000	0.000000000	0.000000000	1.000000000	0.999000000	0.950000000	0.990000000

NR=	0.046635000	RR=	0.013351635	R3=	0.000012696	R10=	0.000000661	RVO=	0.000000006	SVO=	0.000000000

TOTALS

NR=	5.473487653	RR=	0.111407156	R3=	0.000093131	R10=	0.000008965	RVO=	0.000000507	SVO=	0.000009554

SUMMARY OF RESULTS

	NR	RR	R3	R10	RVO	SVO
Table B-3 TOTALS	5.5	.11	9.3 E-5	9.0 E-6	5.1 E-7	9.6 E-6
Event T-15	.01	.009	8.6 E-6	4.5 E-7	4.5 E-0	____
GRAND TOTALS	5.5	.12	1.0 E-4	9.4 E-6	5.1 E-7	9.6 E-6

Table B-4: Post-TMI Baseline, Node Prob'& Event Freq Modified

Event	Frequency	A	B	C	D1	D2	E	F	G	H
T1:Loss MF	3.000000000	0.990000000	0.450000000	0.990000000	0.010000000	0.001000000	0.999000000	0.999000000	0.975000000	0.995000000
T2:1 OS AC	0.200000000	0.990000000	0.450000000	0.990000000	0.010000000	0.001000000	0.999000000	0.999000000	0.975000000	0.995000000
T3:1 NO AC	0.000007000	0.990000000	0.450000000	0.990000000	0.010000000	0.001000000	0.999000000	0.999000000	0.975000000	0.995000000
T4:T TRIP	1.000000000	0.999500000	0.450000000	0.990000000	0.001000000	0.001000000	0.999000000	0.999000000	0.975000000	0.995000000
T5:LD REJ	1.000000000	0.950000000	0.450000000	0.990000000	0.100000000	0.010000000	0.999000000	0.999000000	0.975000000	0.995000000
T6:MSIV cl	0.100000000	0.900000000	0.450000000	0.990000000	0.200000000	0.020000000	0.999000000	0.999000000	0.975000000	0.995000000
T7A:In SI	0.050000000	0.870000000	0.450000000	0.990000000	0.100000000	0.001000000	0.999000000	0.999000000	0.600000000	0.950000000
T8:MF Rupt	0.002000000	0.995000000	0.450000000	0.990000000	0.010000000	0.001000000	0.999000000	0.999000000	0.600000000	0.950000000
T9A:MS Rup	0.002000000	0.870000000	0.450000000	0.990000000	0.100000000	0.001000000	0.999000000	0.999000000	0.600000000	0.950000000
T10:CVCS	0.030000000	0.999000000	0.450000000	0.990000000	0.001000000	0.001000000	0.999000000	0.999000000	0.975000000	0.995000000

Event	NR=	RR=	R3=	R10=	RVO=	SVO=
T1:Loss MF	2.986468650	0.013517805	0.000013030	0.000000332	0.000000001	0.000000179
T2:1 OS AC	0.199097910	0.000901187	0.000000868	0.000000022	0.000000000	0.000000011
T3:1 NO AC	0.000006968	0.000000031	0.000000000	0.000000000	0.000000000	0.000000000
T4:T TRIP	0.999776972	0.000222804	0.000000217	0.000000005	0.000000000	0.000000000
T5:LD REJ	0.974952500	0.025022229	0.000021717	0.000000554	0.000000002	0.000002995
T6:MSIV cl	0.094436000	0.005558346	0.000004343	0.000000110	0.000000000	0.000001198
T7A:In SI	0.046743825	0.003252915	0.000001737	0.000001100	0.000000057	0.000000363
T8:MF Rupt	0.001995489	0.000004505	0.000000002	0.000000001	0.000000000	0.000000000
T9A:MS Rup	0.001869753	0.000130116	0.000000069	0.000000044	0.000000002	0.000000014
T10:CVCS	0.029986618	0.000013368	0.000000013	0.000000000	0.000000000	0.000000000

T11:RC Flw	A	B	C	D1	D2	E	F	G	H
0.120000000	0.995000000	0.450000000	0.990000000	0.001000000	0.001000000	0.999000000	0.999000000	0.975000000	0.995000000

NR=	RR=	R3=	R10=	RVO=	SVO=
0.119732367	0.000267364	0.000000260	0.000000006	0.000000000	0.000000000

T12:T11 AL	A	B	C	D1	D2	E	F	G	H
0.010000000	0.975000000	0.450000000	0.990000000	0.010000000	0.001000000	0.999000000	0.999000000	0.975000000	0.995000000

NR=	RR=	R3=	R10=	RVO=	SVO=
0.009887238	0.000112648	0.000000108	0.000000002	0.000000000	0.000000001

T13:RCP	A	B	C	D1	D2	E	F	G	H
0.001000000	0.750000000	0.450000000	0.990000000	0.200000000	0.010000000	0.999000000	0.999000000	0.975000000	0.995000000

NR=	RR=	R3=	R10=	RVO=	SVO=
0.000860900	0.000138959	0.000000108	0.000000002	0.000000000	0.000000028

T14:Bank	A	B	C	D1	D2	E	F	G	H
0.010000000	0.990000000	0.450000000	0.990000000	0.001000000	0.001000000	0.999000000	0.999000000	0.975000000	0.995000000

NR=	RR=	R3=	R10=	RVO=	SVO=
0.009955394	0.000044560	0.000000043	0.000000001	0.000000000	0.000000000

T16:SG Tub	A	B	C	D1	D2	E	F	G	H
0.060000000	0.500000000	0.450000000	0.990000000	0.000000000	0.000000000	1.000000000	0.999000000	0.975000000	0.995000000

NR=	RR=	R3=	R10=	RVO=	SVO=
0.046635000	0.013351635	0.000013030	0.000000332	0.000000001	0.000000000

TOTALS

NR=	RR=	R3=	R10=	RVO=	SVO=
5.522405584	0.062538472	0.000055545	0.000002511	0.000000063	0.000004789

SUMMARY OF RESULTS

	NR	RR	R3	R10	RVO	SVO
Table B-4 TOTALS	5.5	.06	5.6 E-5	2.5 E-6	6.3 E-8	4.8 E-6
Event T-15	.001	.001	8.8 E-7	2.2 E-8	1.1 E-10	
GRAND TOTALS	5.5	.06	5.7 E-5	2.5 E-6	6.3 E-8	4.8 E-6

TABLE B-5 POST-TMI BOUNDING VALUES: PORV

Case	Value	A	B	C	D1	D2	E	F	G	H
T1:Loss MF	3.000000000	0.990000000	1.000000000	0.990000000	0.010000000	0.001000000	0.989000000	0.989000000	0.600000000	0.950000000
T2:1 OS AC	0.200000000	0.990000000	1.000000000	0.990000000	0.010000000	0.001000000	0.989000000	0.989000000	0.600000000	0.950000000
T3:1 NO AC	0.000007000	0.990000000	1.000000000	0.990000000	0.010000000	0.001000000	0.989000000	0.989000000	0.600000000	0.950000000
T4:T TRIP	1.000000000	0.999500000	1.000000000	0.990000000	0.001000000	0.001000000	0.989000000	0.989000000	0.600000000	0.950000000
T5:LD REJ	1.000000000	0.950000000	1.000000000	0.990000000	0.100000000	0.010000000	0.989000000	0.989000000	0.600000000	0.950000000
T6:MSIV cl	0.100000000	0.900000000	1.000000000	0.990000000	0.200000000	0.020000000	0.989000000	0.989000000	0.600000000	0.950000000
T7A:In SI	0.050000000	0.870000000	1.000000000	0.990000000	0.100000000	0.001000000	0.989000000	0.989000000	0.600000000	0.950000000
T8:MF Rupt	0.002000000	0.995000000	1.000000000	0.990000000	0.010000000	0.001000000	0.989000000	0.989000000	0.600000000	0.950000000
T9A:MS Rup	0.002000000	0.870000000	1.000000000	0.990000000	0.100000000	0.001000000	0.989000000	0.989000000	0.600000000	0.950000000
T10:CVCS	0.030000000	0.999000000	1.000000000	0.990000000	0.001000000	0.001000000	0.989000000	0.989000000	0.600000000	0.950000000

Case	NR=	RR=	R3=	R10=	RVO=	SVO=
T1:Loss MF	2.970297000	0.029375943	0.000196017	0.000124144	0.000006533	0.000000359
T2:1 OS AC	0.198019800	0.001958396	0.000013067	0.000008276	0.000000435	0.000000023
T3:1 NO AC	0.000006930	0.000000068	0.000000000	0.000000000	0.000000000	0.000000000
T4:T TRIP	0.999504995	0.000489554	0.000003266	0.000002069	0.000000108	0.000000005
T5:LD REJ	0.950450000	0.048999564	0.000326664	0.000206887	0.000010888	0.000005995
T6:MSIV cl	0.090080000	0.009808725	0.000065325	0.000041372	0.000002177	0.000002398
T7A:In SI	0.043558500	0.006370573	0.000042470	0.000026898	0.000001415	0.000000142
T8:MF Rupt	0.001990099	0.000009791	0.000000065	0.000000041	0.000000002	0.000000000
T9A:MS Rup	0.001742340	0.000254822	0.000001698	0.000001075	0.000000056	0.000000005
T10:CVCS	0.029970299	0.000029373	0.000000196	0.000000124	0.000000006	0.000000000

T11:RC Flw	A	B	C	D1	D2	E	F	G	H
0.120000000	0.995000000	1.000000000	0.990000000	0.001000000	0.001000000	0.989000000	0.989000000	0.600000000	0.950000000

NR= 0.119405994 RR= 0.000587465 R3= 0.000003920 R10= 0.000002482 RVO= 0.000000130 SVO= 0.000000006

T12:T11 AL	A	B	C	D1	D2	E	F	G	H
0.010000000	0.975000000	1.000000000	0.990000000	0.010000000	0.001000000	0.989000000	0.989000000	0.600000000	0.950000000

NR= 0.009752475 RR= 0.000244799 R3= 0.000001633 R10= 0.000001034 RVO= 0.000000054 SVO= 0.000000002

T13:RCP	A	B	C	D1	D2	E	F	G	H
0.001000000	0.750000000	1.000000000	0.990000000	0.200000000	0.010000000	0.989000000	0.989000000	0.600000000	0.950000000

NR= 0.000752000 RR= 0.000245245 R3= 0.000001633 R10= 0.000001034 RVO= 0.000000054 SVO= 0.000000032

T14:Bank	A	B	C	D1	D2	E	F	G	H
0.010000000	0.990000000	1.000000000	0.990000000	0.001000000	0.001000000	0.989000000	0.989000000	0.600000000	0.950000000

NR= 0.009900999 RR= 0.000097910 R3= 0.000000653 R10= 0.000000413 RVO= 0.000000021 SVO= 0.000000001

T16:SG Tub	A	B	C	D1	D2	E	F	G	H
0.060000000	0.500000000	1.000000000	0.990000000	0.000000000	0.000000000	0.989000000	0.989000000	0.600000000	0.950000000

NR= 0.030300000 RR= 0.029373300 R3= 0.000196020 R10= 0.000124146 RVO= 0.000006534 SVO= 0.000000000

TOTALS

NR= 5.455731431 RR= 0.127845528 R3= 0.000852627 R10= 0.000539995 RVO= 0.000028413 SVO= 0.000008968

SUMMARY OF RESULTS

	NR	RR	R3	R10	RVO	SVO
Table B-5 TOTALS x 15	81.8	1.92	1.3 E-2	8.1 E-3	4.3 E-4	1.3 E-4
Event T-15	0	0	1.2 E-3	7.6 E-4	4.0 E-5	0
GRAND TOTALS	81.8	1.92	1.4 E-2	8.9 E-3	4.7 E-4	1.3 E-4

TABLE B-6 POST-TMI BOUNDING VALUES: SRV

T1:Loss MF	A	B	C	D1	D2	E	F	G	H
3.000000000	0.990000000	0.000000000	0.990000000	0.010000000	0.001000000	0.989000000	0.989000000	0.600000000	0.950000000

NR= 2.999700000 RR= 0.000296700 R3= 0.000000000 R10= 0.000000000 RVO= 0.000000000 SVO= 0.000003300

T2:1 OS AC	A	B	C	D1	D2	E	F	G	H
0.200000000	0.990000000	0.000000000	0.990000000	0.010000000	0.001000000	0.989000000	0.989000000	0.600000000	0.950000000

NR= 0.199980000 RR= 0.000019780 R3= 0.000000000 R10= 0.000000000 RVO= 0.000000000 SVO= 0.000000220

T3:1 NO AC	A	B	C	D1	D2	E	F	G	H
0.000007000	0.990000000	0.000000000	0.990000000	0.010000000	0.001000000	0.989000000	0.989000000	0.600000000	0.950000000

NR= 0.000006999 RR= 0.000000000 R3= 0.000000000 R10= 0.000000000 RVO= 0.000000000 SVO= 0.000000000

T4:T TRIP	A	B	C	D1	D2	E	F	G	H
1.000000000	0.999500000	0.000000000	0.990000000	0.001000000	0.001000000	0.989000000	0.989000000	0.500000000	0.950000000

NR= 0.999999500 RR= 0.000000494 R3= 0.000000000 R10= 0.000000000 RVO= 0.000000000 SVO= 0.000000005

T5:LD REJ	A	B	C	D1	D2	E	F	G	H
1.000000000	0.950000000	0.000000000	0.990000000	0.100000000	0.010000000	0.989000000	0.989000000	0.600000000	0.950000000

NR= 0.995000000 RR= 0.004945000 R3= 0.000000000 R10= 0.000000000 RVO= 0.000000000 SVO= 0.000055000

T6:MSIV cl	A	B	C	D1	D2	E	F	G	H
0.100000000	0.900000000	0.000000000	0.990000000	0.200000000	0.020000000	0.989000000	0.989000000	0.600000000	0.950000000

NR= 0.098000000 RR= 0.001978000 R3= 0.000000000 R10= 0.000000000 RVO= 0.000000000 SVO= 0.000022000

T7A:In SI	A	B	C	D1	D2	E	F	G	H
0.050000000	0.870000000	0.000000000	0.990000000	0.100000000	0.001000000	0.989000000	0.989000000	0.600000000	0.950000000

NR= 0.049350000 RR= 0.000642850 R3= 0.000000000 R10= 0.000000000 RVO= 0.000000000 SVO= 0.000007150

T8:MF Rupt	A	B	C	D1	D2	E	F	G	H
0.002000000	0.995000000	0.000000000	0.990000000	0.010000000	0.001000000	0.989000000	0.989000000	0.600000000	0.950000000

NR= 0.001999900 RR= 0.000000098 R3= 0.000000000 R10= 0.000000000 RVO= 0.000000000 SVO= 0.000000001

T9A:MS Rup	A	B	C	D1	D2	E	F	G	H
0.002000000	0.870000000	0.000000000	0.990000000	0.100000000	0.001000000	0.989000000	0.989000000	0.600000000	0.950000000

NR= 0.001974000 RR= 0.000025714 R3= 0.000000000 R10= 0.000000000 RVO= 0.000000000 SVO= 0.000000286

T10:CVCS	A	B	C	D1	D2	E	F	G	H
0.030000000	0.999000000	0.000000000	0.990000000	0.001000000	0.001000000	0.989000000	0.989000000	0.600000000	0.950000000

NR= 0.029999970 RR= 0.000000029 R3= 0.000000000 R10= 0.000000000 RVO= 0.000000000 SVO= 0.000000000

T11:RC Flw	A	B	C	D1	D2	E	F	G	H
0.120000000	0.995000000	0.000000000	0.990000000	0.001000000	0.001000000	0.989000000	0.989000000	0.600000000	0.950000000

NR=	0.119999400	RR=	0.000000593	R3=	0.000000000	R10=	0.000000000	RVO=	0.000000000	SVO=	0.000000006

T12:T11 AL	A	B	C	D1	D2	E	F	G	H
0.010000000	0.975000000	0.000000000	0.990000000	0.010000000	0.001000000	0.989000000	0.989000000	0.600000000	0.950000000

NR=	0.009997500	RR=	0.000002472	R3=	0.000000000	R10=	0.000000000	RVO=	0.000000000	SVO=	0.000000027

T13:RCP	A	B	C	D1	D2	E	F	G	H
0.001000000	0.750000000	0.000000000	0.990000000	0.200000000	0.010000000	0.989000000	0.989000000	0.600000000	0.950000000

NR=	0.000950000	RR=	0.000049450	R3=	0.000000000	R10=	0.000000000	RVO=	0.000000000	SVO=	0.000000550

T14:Bank	A	B	C	D1	D2	E	F	G	H
0.010000000	0.990000000	0.000000000	0.990000000	0.001000000	0.001000000	0.989000000	0.989000000	0.600000000	0.950000000

NR=	0.009999900	RR=	0.000000098	R3=	0.000000000	R10=	0.000000000	RVO=	0.000000000	SVO=	0.000000001

T16:SG Tub	A	B	C	D1	D2	E	F	G	H
0.060000000	0.500000000	0.000000000	0.990000000	0.000000000	0.000000000	0.989000000	0.989000000	0.600000000	0.950000000

NR=	0.060000000	RR=	0.000000000	R3=	0.000000000	R10=	0.000000000	RVO=	0.000000000	SVO=	0.000000000

TOTALS

NR=	5.576957169	RR=	0.007961278	R3=	0.000000000	R10=	0.000000000	RVO=	0.000000000	SVO=	0.000088546

SUMMARY OF RESULTS

	NR	RR	R3	R10	RVO	SVO
Table B-6 TOTALS x 15	83.6	0.12				1.3 E-3
Event T-15	0	0				0
GRAND TOTALS	83.6	0.12				1.3 E-3