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DEPENDENT HUMAN ERROR PROBABILITY ASSESSMENT

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ABSTRACT

This paper presents an dynamic operator actions dependence assessment modeled in a Nuclear Power Plant (NPP) PRA and estimate the associated impact on core damage frequency. This assessment was done to improve HEP dependencies implementation inside existing PRA.

All of the dynamic operator actions modeled in the NPP PRA are included in this assessment.

Determining the "level" of human error probability (HEP) dependence and the associated influence on core damage frequency (CDF) are the major steps of this assessment. A decision on how to apply the results, i.e., should permanent HEP model changes be made, is based on the resulting relative CDF increase. Some CDF increase was selected as a threshold based on the NPP base CDF value and acceptance guidelines from the Regulatory Guide 1.174. HEP dependence resulting in a CDF increase of > 5E-07 would be considered potential candidates for specific incorporation into the baseline model.

The approach used to judge the level of dependence between operator actions is based on dependency level categories and conditional probabilities developed in the "Handbook of Human Reliability Analysis with Emphasis on Nuclear Power Plant Applications" NUREG/CR-1278. To simplify the process, NUREG/CR-1278 identifies five levels of dependence: ZD (zero dependence), LD (low dependence), MD (moderate dependence), HD (high dependence), and CD (complete dependence). NUREG/CR-1278 also identifies several qualitative factors that could be involved in determining the level of dependence. Based on the NUREG/CR-1278 information, Time, Function, and Spatial attributes were judged to be the most important considerations when determining the level of dependence between operator actions within an accident sequence.

These attributes were used to develop qualitative criteria (rules) that were used to judge the level of dependence (CD, HD, MD, LD, ZD) between the operator actions. After the level of dependence between the various HEPs is judged, quantitative values associated with the level of dependence is assigned and used in a quantitative sensitivity assessment.

Based on the systematic framework for analysis of human action dependency from this paper it can be concluded that many HEPs are already modeled as complete dependence (CD) in the current PRA model. Likewise, many of the HEPs were judged to have zero influence (zero dependency) on other HEPs in the same sequence. Only a few HEPs were judged to have some level of dependence other than zero or complete that was not already captured in the NPP PRA model. These HEPs were candidates for quantitative assessment to determine the impact on CDF using the postulated threshold.

The quantitative impact on CDF from the newly identified dependent HEPs was evaluated in several iterations because of the NPP PRA model structure.

The final dependent HEP impact on CDF was quantified by assessing only the contribution of the sequences containing the dependent HEPs where the top event, which contains the influencing HEP, is also failed. This was performed by comparing the top events sequences from the base case NPP PRA model to a model with top events containing the dependent HEP values. The dependent HEP-relevant sequences were selected from a list of more then 10,000 base case sequences. There were total of 50 dependent HEP related sequences captured in all of the 10,000 sequences. Based on the assessment of the HEPs, the increase in CDF as a result of the human actions dependence is very small. The total CDF with the human action dependence is also relatively small.

1 INTRODUCTION

The purpose of this evaluation is to reassess the level of dependence between dynamic operator actions modeled in the Nuclear Power Plant PRA and than to estimate the potential impact on CDF. This evaluation was performed in order to address a Category A finding identified during the Peer Review Certification of the NPP PRA.

The approach used to judge the level of dependence between operator actions is based on dependency level categories and conditional probabilities developed in the "Handbook of Human Reliability Analysis with Emphasis on Nuclear Power Plant Applications" NUREG/CR-1278, Reference [2].

All of the dynamic operator actions modeled in the NPP PRA are included in this assessment. The NPP PRA models the dynamic operator actions both within the fault trees and directly in the event trees.

Description of the approach used for the human action dependency assessment is presented in Section 2 of this paper. Section 3 provides a conclusion regarding the influence that human action dependency has on CDF.

Separate Appendices are included for illustration purposes: (A) lists selected the human actions included in this assessment, and (B) provides the event tree dependency matrixes used to record the level of dependence judged between each action.

2 HEP DEPENDENCY ASSESSMENT

This section summarizes the approach taken to assess the human action dependency. Figure 1 presents a flowchart for the human action dependency assessment process. Determining the level of HEP dependence and the associated influence on CDF from HEP dependence not already captured in the PRA are the major steps. A decision on how to apply the results, i.e., should permanent HEP model changes be made, is based on the relative CDF increase. A CDF increase of 5E-07 is selected as a threshold based on the NPP base CDF value (approximatly 5E-06) and acceptance guidelines from the Regulatory Guide 1.174, Reference [1].

Background information and the methodology used in this assessment are presented in the first subsection. Second subsection presents the rules to assess the level of dependency between operator actions, e.g., complete, high, moderate, low, zero dependency. Finally, the third subsection presents the assessment of the identified dependent human actions influence to the CDF quantification.

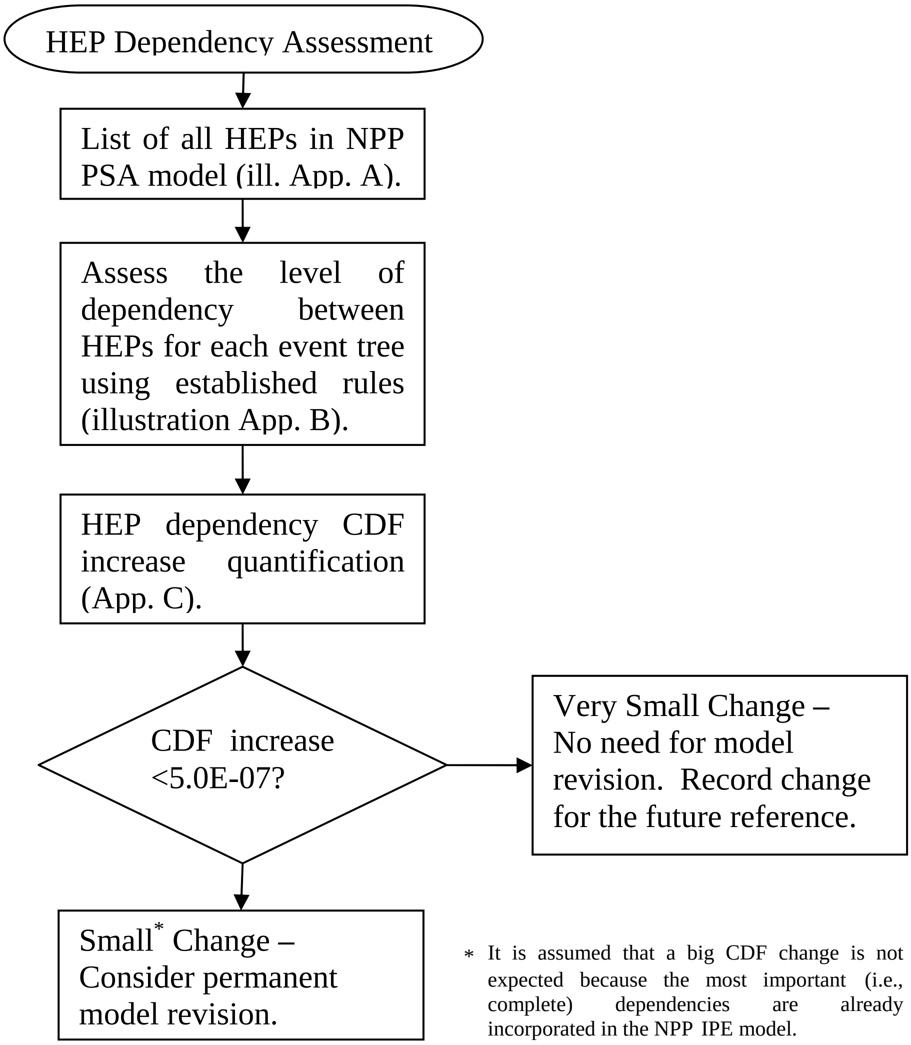

Figure 1: Top Level Human Actions Dependency Assessment Framework

2.1 Background

The peer review certification findings relating to lack of systematic treatment of HEP dependence is as follows:

When more than one operator action occurs in a sequence or a cutset, it must be determined whether the failure probability of the second operator action is affected by the failure of the first operator action. …

There appears to be lack of a systematic process for discovering and modeling potential dependencies.

The peer review team offered the following suggestion to accomplish the HEP dependency assessment.

Vary the HEP's in sensitivity studies to identify sequences with potential human error dependence. Evaluate each important sequence individually to assess and estimate this dependence. Provide conditional split fractions as needed to replace the probabilities of the subsequent actions with values that reflect the dependence.

The peer review certification team assessed this observation as a Category A. However, it seem that there are reasons to believe this is not a significant issue because it does not have a significant effect on the PRA results based on the following:

1. There is a large amount of judgment applied to the development of the point estimates for the individual HEPs. Given the state-of-the-art, there is no sound technical basis that is applicable to development of dependent HEPs in the context of our models and reality, i.e., where multiple operators and multiple crews are involved in decision making (cognitive error) and implementing associated actions (manipulative error), and where significant time can exist between human actions of interest.
2. The existing NPP PRA model does not credit recovery from a failed action, which is a conservative approach. In fact, very little recovery of any kind is credited in the PRA.
3. Many HEPs in the NPP PRA are modeled as "completely" dependent. This means that, for such actions, failure of the first action is assumed to directly cause failure of another (one or more) downstream action.
4. As mentioned in the response to the NRC's request for additional information (RAI) on the NPP IPE, the PRA model considered dependence between the significant human actions during development of the accident sequence model. Failure of many of these actions is conservatively assumed to result in core damage.

Quantitative methodology used in the NPP PRA is so called "small fault tree / large event tree" methodology. Given this approach, it is difficult to perform a rigorous quantitative dependency assessment without a significant overhaul of the entire model/process. Such an overhaul of the model is not practical to perform and would not yield significantly meaningful insights. Furthermore, such an overhaul would be very expensive and is likely to make the model unmanageable. Therefore, a qualitative approach coupled with a sensitivity assessment is performed to address treatment of HEP dependence and will be based on the best available HEP methodology information.

This HEP dependency assessment uses information described in Section 10 of the "Handbook of Human Reliability Analysis with Emphasis on Nuclear Power Plant Applications" (NUREG/CR-1278), Reference [2]. Aspects of the NUREG/CR-1278 methodology and applicability to this assessment are summarized below.

NUREG/CR-1278 identifies several qualitative factors that could be involved in determining the level of dependence. General guidance for qualitatively assessing the level of dependence is outlined in the NUREG/CR-1278 Table 10-1. Unfortunately, NUREG/CR-1278 lacks specific insights on how all of the factors associated with dependence are defined. NUREG/CR-1278 illustrates only one graph (Figure 10-5), which identifies quantitative attributes about time and spatial factors. Based on this illustration, ZD (zero dependence) would be assumed if time between tasks exceeds more than 60 seconds, or if the operator must walk to a different panel/location to perform the next task. NUREG/CR-1278 is primarily focused on evaluation of dependency between the tasks inside one operator action, for example: reading two instruments when they are located close together or calibrating equipment or aligning valves that are detailed within a step by step procedure. Based on this information, however, Time, Function, and Spatial attributes are judged to be the most important considerations when determining the level of dependence.

The following quotes are taken directly from NUREG/CR-1278:

"*There are no hard and fast rules for deciding what level of dependence is appropriate for any situation; considerable judgement is required.*" (p 10-14), and

"*We usually assume ZD when estimating the error probabilities for carrying out individual steps in a <u>written procedure</u>.*" (p 10-16).

To simplify the process, NUREG/CR-1278 has reduced the number of dependent levels to five. The levels of dependence are: ZD (zero dependence), LD (low dependence), MD (moderate dependence), HD (high dependence), and CD (complete dependence).

The initial step in assessing the human action dependence is to judge the level of dependence. This is done by assessing the human actions modeled in each event tree against qualitative criteria. After the level of dependence between the various HEPs (limited to two HEPs) is judged, quantitative values associated with the level of dependence is assigned and used in a quantitative sensitivity assessment.

The quantitative model for these dependency levels (from Table 10-2 of NUREG/CR-1278) is shown below (Table 1). These quantitative values will be used in the quantitative sensitivity assessment.

Table 1 Equations for Conditional Probabilities of Human Action Failure Given Failure of Previous Human Action for Different Levels of Dependence

Dependency Level		**Conditional HEP Equation**
Zero Dependence	**ZD**	λ (basic human error probability)*
Low Dependence	**LD**	$(1 + 19\lambda) / 20$
Moderate Dependence	**MD**	$(1 + 6\lambda) / 7$
High Dependence	**HD**	$(1 + \lambda) / 2$
Complete Dependence	**CD**	1.0

Based on the above, dependence between human error probabilities (HEPs) will be determined primarily according to their attributes of function, time, and spatial relationships.

2.2 Rules for Assessing the Level of HEP Dependence

Two rules are defined in order to systematicaly determine HEP dependencies, and their description follows.

Rule #1 for Assessing the Level of HEP Dependencies Based on time, spatial, and functionalconsideration

Time, spatial and functional considerations as base for HEP dependency determination are provided below in Table 4 and Table 5. In order to illustrate approach an example of Rule #1 application for “moderate dependence” between actions involving the same function is presented: Rule 1AM2, where: “1” refers to rule 1, “A” refers to Table 4 (same functions), “M” refers to medium time window available, and “2” refers to medium spatial dependence.

Grouping for the available time to perform two operator actions is established based on information from the NUREG/CR-1278 (i.e., Figure 10-5) and judgment relative to a 30 minute time window for execution of the actions. In order to avoid extreme conservatism available time longer than 12 hours was defined as a separate group. Table 2 presents the groups formed based on available time.

Operator action dependency influenced by spatial similarity is grouped based on information from the NUREG/CR-1278 and judgment. Table 4 presents the spatial dependency groups.

Table 2 Available Time Groups

Available Time	**Group**	**Description**
Short	S	Both actions needed in less than approximately 30 minutes.
Medium	M	At least one action has more than approximately 30 minutes.
Long	L	Both actions have more than approximately 30 minutes.
Long-Long	E	One or more actions have longer than 12 hours.

Table 3 Spatial Dependency Groups

Spatial Dependency	**Group**	**Description**
High	1	Same control room panel or same operator.
Medium	2	Different control room panels but are adjacent/in proximity.
Low	3	Different control room panels with separation (not side by side), or different operator or control room vs. local operation

Table 4 HEP Dependency Assessment Involving Same Functions – "A"

Actions involving SAME Functions		**Available Time**			
		Short (S)	**Med (M)**	**Long (L)**	**Long-Long (E)**
Spatial Dependency	**High (1)**	**CD**	**HD**	**MD**	**ZD**
	Medium (2)	**HD**	**MD**	**LD**	**ZD**
	Low (3)	**MD**	**LD**	**ZD**	**ZD**

Table 5 HEP Dependency Assessment Involving Different Functions – "B"

Actions involving DIFFERENT Functions		**Available Time**			
		Short (S)	**Med (M)**	**Long (L)**	**Long-Long (E)**
Spatial Dependency	**High (1)**	**HD**	**MD**	**LD**	**ZD**
	Medium (2)	**MD**	**LD**	**ZD**	**ZD**
	Low (3)	**LD**	**ZD**	**ZD**	**ZD**

Rule #2 for Assessing the Level of HEP Dependencies as Complete Dependence (CD) Based on Component/System Dependence

Complete dependence (CD) to HEP is assigned, without applying Rule #1, when the human actions involve components or systems that share complete dependence. For example, if the operator action to depressurize the RPV fails, the operator action to initiate low pressure ECCS is also failed. This dependency is indicated in the HEP dependency matrices as complete dependency (CD), and reflects the event tree structure of the NPP model.

All HEPs in the NPP PRA model were covered using the above rules. Selected HEPs included in the assessment are listed in Appendix A (for the illustration). The "level" of dependence is recorded in the event tree matrices provided in Appendix B (for the illustration). The rule applied to judge the level of dependence is indicated on the matrices with supporting notes.

2.3 HEP Dependency Quantification

Human action dependency level assessed in Section 2 is the starting point for the core damage frequency change quantification.

Table 6 lists all dependent human actions (HA) identified in the HA assessment which are not already accounted for in the baseline PSA model and their resulting dependent (conditional) probabilities (conservatively rounded). Baseline NPP PSA model has already captured numerous cases of complete dependency between various human actions.

The new dependent HEP, after the influencing HEP has failed, is depending on the failed HEP and dependency level and it is defined with relations from Table 1 as taken from NUREG/CR-1278, Reference [2].

Table 6 NPP Dependent Human Errors

#	Event Tree	Influencing		Dependent		
		Top	HEP	Top	HEP	
					(Dependency Level)	New HEP Value
1	**AUX**	RW	HEP01	**TW**	HEP02 (MD)	0.15
2	**MLOCA**	HP	HEP03	**LP** **CS (OI)**	HEP04 (LD) HEP05 (LD)	0.1* 0.1*
3	**SLOCA**	HP and RC	HEP03	**LP** **CS (OI)**	HEP04 (MD) HEP05 (MD)	0.15 0.15
4	**Transient**	RC and HP	HEP03	**LP** **CS (OI)**	HEP04 (MD) HEP05 (MD)	0.15 0.15
5	**ATWS**	FW	HEP06	**LC** **LI**	HEP07 (HD), HEP08 (HD) HEP09 (HD)	0.5 0.5 0.5
		RM	HEP10, HEP12	**OT**	HEP11(MD)	0.15

* Conservatively rounded.

Event Trees without new dependent HEPs are the following: ELEC, LLOCA, ISLOCAL, ISLOCAS, and LOCAOC.

The quantitative impact from HEP dependency was evaluated in several iterations because of the structure of NPP PSA model. New HEP values used for the model requantification are rounded.

The first iteration was to include all new dependent HEP values and estimate the most conservative impact. This was the most conservative because dependent HEPs were included in the complete model (i.e., they increased sequence frequency regardless of the failure or success of the preceding influencing HEP).

The second iteration was to quantify the contribution of the dependent HEP to CDF by only accounting for the sequences where the influencing HEPs failed. This is performed by comparing split fraction sequences between the base and DHEP model. This is performed for all but OI related dependent HEPs because they were proved to have negligible contribution to CDF (analyzed Cases 2 & 3 not covered in details within this paper).

Table 7 NPP PSA RISKMAN HEP Dependency Related Analytical Cases

#	Analyzed Case	PSA Model & MFF	CDF [%]	Comment
1	Base	NPP00, NPPFF00	100,0	Model without DHEP
2	DHEP	NPP00DHOI, NPP1F00DO	248,5	Model with all DHEP included.
3	DHEP W/OI	NPP00DHEP NPP1F00FH	248,5	Model with included all but OI related DHEP.

Relevant sequences have to contain both the influencing HEP related SF and the dependent HEP related SF.

Model DHEP relevant sequences were selected from the list of more then 10,000 base case sequences. There were 50 DHEP model related sequences. Each DHEP model related sequence is contributing to the CDF equal to the difference in frequency for the DHEP and Base analyzed case. (Further details are not covered within this paper.)

It is important to notice that the final estimate has to take in to consideration the fact that the total probability of failure for the influencing split fractions is not contributed 100% from the associated influencing HEP. More details are provided in the Appendix C. Therefore a more detail analysis of the 50 contributing sequences from DHEP model shows that a more precise estimate of DHEP CDF increase is about five times lower. This is a CDF increase of **0,6%**. The CDF as a result of the dependent HEPs is then for illustration:

5E-06	+	3E-08	=	**5.03E-06 [1/yr]**
(Base case CDF)		(CDF contribution from the DHEP)		**(CDF with the DHEP)**

This is little more then **0.6%** increase from the base CDF. It can be concluded that the CDF increase because of the additional human action dependency modeling is negligible.

3 CONCLUSION

Based on the systematic framework for analysis of human error dependency from this paper, it can be concluded that most important dependencies (i.e., complete) are already captured inside the existing NPP IPE model. New found dependencies are only for the operator actions listed in the Table 6.

Total contribution to the NPP base CDF value is quantified in as 3E-8. This is an increase of about 0.6%. Based on the general approach outlined in Section 2, it can be concluded that this very small change and does not warrant a need for permanent NPP IPE model changes.

REFERENCES

[1] U.S. NRC, "*An Approach for Using Probabilistic Risk Assessment In Risk-Informed Decisions On Plant-Specific Changes to the Licensing Basis*," Regulatory Guide 1.174, July 1998

[2] A. D. Swain, H. E. Guttman, "*Handbook of Human Reliability Analysis with Emphasis on Nuclear Power Plant Applications*", Final Report, NUREG/CR-1278, August 1983

[3] Nuclear Power Plant Probabilistic Risk Assessment and Human Reliability Analysis

APPENDIX A: DYNAMIC OPERATOR ACTIONS IN NPP EVENT TREES

This Appendix presents sample of operator actions from the NPP IPE PSA model. Human actions are grouped by associated top events, briefly described and accompanied with information about available time for execution and estimated probability of failure.

Operator actions are separately presented in the two tables: Operator actions modeled as a part of the Electrical and Auxiliary Support Event Trees - Table 8, and Operator actions modeled as a part of the Frontline Event Trees - Table 9.

Table 8 Dynamic Operator Actions in NPP Electrical and Auxiliary Support Event Trees

Top Event	Operator Action Description	Basic Event Time Window HEP Value	Event Tree
GA	Emergency Diesel Generator 1A: - Failure to recover D/G fuel oil transfer (HEP20). Note: This action was originally modeled for sequences that include loss of instrument air and dependent closure of the fuel oil transfer valves (AOVs). However, the fuel oil transfer valves are now blocked in the open position and this action is no longer evaluated in the model.	N/A	ELEC
VN	VT: Failure to establish the VT to either Bus 3 or Bus 4 by remotely operated breakers from within the control room (HEP21). Controls for the VT breakers are located on Control Room Panel CRP 9-8.	**HEP21** 30 min. 0,0012	ELEC
C1	Long term 125V DC-1: Failure to align the spare battery charger given random failure of the normal charger (HEP30). This action is performed in the Cable Vault.	**HEP30** 4 hrs. 0,01	ELEC

Table 9 Dynamic Operator Actions in NPP Frontline Event Trees

Top Event	Operator Action Description	Basic Event Time Window HEP Value	Event Tree
AD	Manual RPV Depressurization: Failure to initiate RPV depressurization during small LOCA/Transient conditions (HEP40). ADS controls are located at Control Room Panel CRP 9-3.	**HEP40** 66 min. 0,00021	SLOCA TRANS ISLOCAS LOCAOC
IA	Inhibit ADS: Failure to inhibit ADS during an ATWS event with insufficient high level makeup (HEP50). (CRP 9-3)	**HEP50** 6.2 min. 0,0016	ATWS
HP	HPCI: Failure to initiate HPCI/RCIC (HEP60) for transient/SLOCA. MLOCA is action is for HPCI (not RCIC) because RCIC is not credited during Medium LOCA. HEP for Medium LOCA is the same as for transient/SLOCA. Failure to initiate HPCI/RCIC suction transfer to the suppression pool given failure of the automatic transfer on low	**HEP60** 66 min. 2.1E-3 **HEP65** 13 min. 0,0014	MLOCA SLOCA TRANS ISLOCAS
TC	Torus Cooling: Failure to initiate torus cooling during transients and LOCA events. Torus Cooling (RHR) controls are located at Control Room Panel CRP 9-3.	**HEP70** 24 hrs. 1.0E-6	{L, M, S}LOCA TRANS ISLOCA{S, L}

APPENDIX B: HEP DEPENDENCY LEVEL DETERMINATION - DETAILS

This appendix illustrates results of the HEP dependency "level" determination. Details about dependency level determination process are described under Section 2. HEP dependency level determination results are presented in a separate matrix for each event tree. One matrix is presented here for illustration: Operator Action Dependence within Large LOCA Tree - Table 10.

Each individual HEP dependency level determination in the matrix is further explained with reference to the rule applied and, when necessary, with additional supporting notes.

Table 10 Operator Action Dependence within Large LOCA Tree

Top Event	**CR**	**VS**	**LP**	**CS**	**TC**	**VT**	**AI**
Operator Action			Note 4	Note 4	HEP70	HEP80	HEP90
CR	n/a	-	-	-	-	-	-
VS		n/a	-	-	-	-	-
LP			n/a	-	-	-	-
CS				n/a	-	-	-
TC					n/a	**ZD^{1AL3}** **Note 1**	**ZD^{1BL3}** **Note 2**
VT						n/a	**CD^{2}** **Note 3**
AI							n/a

Legend:

— This designation is used when at least one top event (split fraction) does not include an operator action.

n/a This designation is used when top event (split fraction) has only one operator action.

ZD^n, CD^n, LD^n, MD^n, HD^n, Dependence levels (zero, complete, low, medium, and high) between two operator actions in one or two top events. **n** refers to the rule number applied.

Notes:

1. To judge the dependence between initiation of torus cooling and initiation of the containment vent, it is necessary to consider the following: (1) there is similarity in function, i.e., remove containment heat, but (2) there is a significant amount of time available (12 to 24 hours) to enable the containment vent given torus cooling failure. Given the significant time available, it is clear that actions will be underway to ensure initiation of some mode of containment heat removal. Torus cooling is initiated/controlled from CRP 9-3 and the torus vent valve is controlled from CRP 9-25 in the rear of the control room. Based on the above, zero dependence is judged between the TC and VT operator actions using Rule 1AL3.

2. The large break LOCA event tree only credits AI using split fraction HEP90. This split fraction models the capability to throttle/control containment pressure/venting to preserve NPSH for systems taking suction from the suppression pool. Thus, AI is said to be success if RPV inventory makeup from ECCS systems is success and the vent is controlled to preserve suction supply. The HEP90 function is judged to be different from the action to initiate TC. Also, significant time (approximately 24 hours) is available to perform the TC and/or AI actions. Also, HEP90 is only evaluated after the action to align/enable the torus vent is success. Therefore, considering that VT, which includes HEP95, must first be success and AI success depends on VT success, it is judged that AI actions have zero dependence with TC.

3. The LLOCA tree assumes failure of alternate injection (AI) whenever the containment vent (VT) fails and this reflects complete dependence.

4. No operator actions are credited under LP, CS or OI (Aux. Tree) for initiation of low pressure injection during large break LOCA event.