Appendix E: Quantification of Operator Actions by STAHR Methodology
of
A PRESSURIZED THERMAL SHOCK EVALUATION OF THE CALVERT CLIFFS UNIT 1 NUCLEAR POWER PLANT

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A PRESSURIZED THERMAL SHOCK EVALUATION OF THE CALVERT CLIFFS UNIT 1 NUCLEAR POWER PLANT

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APPENDIX E - QUANTIFICATION OF OPERATOR ACTIONS BY STAHR METHODOLOGY

E.1. Introduction

Soon after its development, the STAHR methodology (a socio-technical approach to assessing human reliability) described in Appendix D was used to quantify the frequencies of error associated with a set of predetermined operator actions at the Calvert Cliffs Unit 1 nuclear power plant. A four-day meeting was held at Combustion Engineering* specifically for this purpose, and although the composition of the group attending the meeting varied somewhat over the four days, the following roles were represented: group consultant and facilitator, technical moderator, trainer of reactor operators, thermo-hydraulic engineer and procedures specialist, pressured thermal shock engineer, probabilistic risk analyst, reliability and systems analyst, human reliability specialist, and reactor operator.+ The two reactor operators present were expecting confirmation of their licensing as senior reactor operators.

At the first session of the meeting, a brief description of the role of human judgment in risk assessments was given, with particular emphasis on the view of probability as an expression of a degree of belief. The conditions under which good calibration of probability assessments could be expected were also described. The group was then charged with the responsibility of applying the STAHR methodology to the preselected target events (operator actions) during the remainder of the meeting. In preparation for this task, the group toured the Combustion Engineering simulator and

*Meeting held at Combustion Engineering, Hartford, Connecticut, May, 1983.

+One of the authors (Phillips) served as the group consultant and another (Embry) served as the human reliability analyst. A member of the PTS study group (Selby of Oak Ridge National Laboratory) acted as the technical moderator.

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engaged in a practice session for one of the target events (which was later reevaluated). This appendix summarizes the deliberations of the group both in the practice session and in subsequent sessions in which the STAHR methodology was applied to target events.

E.2. Practice Session with STAHR Methodology

At the practice session, the group was presented with the list of target events to be considered (see Table E.1). It was recognized that in general all these target events involved determining whether or not an operator would successfully perform some mitigating action. After some discussion, the group selected operator action 4 from the table as the target event for the practice session and defined the following initial conditions* as the "conditioning events":

(1) The target event occurred near the end of the core refueling cycle.

(2) The reactor was at hot 0% power (532°F) (hot standby).

(3) The atmospheric dump valve (ADV) was open.

(4) The main feedwater system was in bypass mode.

The target event as defined by the group was as follows:

*These two actions correspond to steps 1 and 2 in Section D.4 of Appendix D.

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Table E.1. Initial list of target events (operator actions) to be quantified

1. Operator controls repressurization following
    a. A LOCA event which is isolated.
    b. A large steam-line break from full power.
    c. A large steam-line break from hot 0% power.
    d. A small steam-line break from full power.
    e. A small steam-line break from hot 0% power.
2. Operator controls auxiliary feedwater to maintain steam generator level following
    a. A large steam-line break from full power.
    b. A large steam-line break from hot 0% power.
    c. A small steam-line break from full power.
    d. A small steam-line break from hot 0% power.
3. Operator isolates PORV that has failed to close owing to
    a. PORV failure being the initiating event.
    b. PORV failure occurring during repressurization following a separate event.
4. Operator isolates ADV after it has failed to close.
5. Operator stops forced main feed after MFIVs fail to close on SGIS following a steam-line break

Operator will recognize that ADV is open and will isolate ADV line within 30 minutes.

To ensure that all members of the group were reasonably familiar with the technical operation of the system, engineers familiar with Calvert Cliffs Unit 1 described the main steam header and also the main feed valve and bypass valve of the main feedwater system. The group was then introduced to influence diagrams and their relationship to event trees. The influence diagram described from Appendix D was presented, together with definitions of the bottom-level influences. Considerable discussion of the influences followed, with the result that the definitions of the influences were slightly changed and extended. Table E.2 gives the final definitions as they were used throughout the remainder of the week.

Most of the practice session was spent in discussions that helped to generate the assessments required for the target event. It was apparent that the group did not find it particularly easy to make these assessments, and considerable disagreement about the appropriate numbers emerged from the discussions. Eventually, however, consensus judgments emerged, and the unconditional probability of the operator successfully completing the target action was determined to be 0.937. However, because this was the first effort of the group, this figure was not taken very seriously.

E.3. Application of STAHR Methodology to Target Events of Table E.1

During the next several sessions, the group applied the STAHR methodology to all the target events listed in Table E.1. The approaches used and the

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Table E.2. Definitions of lowest-level influences in influence diagram

1. Design of Control Room

	Good	Poor
a. Displays		
	Easy to read and understand and accessible.	Hard to read, difficult to interpret, inaccessible.
	Make sense, easy to relate to controls.	Confusing, not directly related to controls.
	Alarms discriminable, relevant, coded.	Alarms confusing, irrelevant, not coded.
	Mimic display.	Non-representational display.
	Displays regarding event are present, clear, unambiguous.	Displays regarding event are not present, are unclear or ambiguous.
b. Operator involvement		
	Operators have say in modifications.	Operators have little or no say.
	Prompt confirmation of action.	No confirming information.
c. Automation of routine functions		
	Highly automated.	Low level of automation.
	Operators act as systems managers.	Operators perform many routine functions.

2. Meaningfulness of Procedures

	Meaningful	Not meaningful
a. Realism		
	Realistic; the way things are done.	Unrealistic; not the way things are done.
b. Location aids		
	Location aids provided.	Few or no location aids provided.
c. Scrutability		
	Procedures keep operators in touch with plant.	Procedures do not keep operators in touch with plant.
d. Operator involvement		
	Operators involved in developing procedures.	Operators not involved in developing procedures.
e. Diagnostics		
	Allow unambiguous determination of event in progress.	Allow inappropriate diagnosis.

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f. Format

Procedures clear, consistent, and in easily read format.	Procedures confusing, difficult to read.

3. Role of Operations Department

Primary	Not primary
a. Accountability	
All other functions report to operations supervisor.	Only operations staff report to operations supervisor.
b. Relationship to maintenance and other functions	
Good relations.	Antagonism.
c. Paperwork	
About right.	Excessive.
d. Operator involvement	
Operators have a say in how the place is run.	Operators have no say in how place is run.

4. Effectiveness of Teams

Present	Absent
a. Shifts	
Allow teams to stay together.	Prohibit team formation.
b. Roles	
Well-defined accountabilities.	Poorly defined accountabilities.
c. Training	
Teams train together.	Team members not trained together.

5. Level of Stress

Helpful	Level not helpful
a. Shifts	
No jet lag.	Permanent jet lag.
b. Time available	
Adequate	Too little.
c. Operating objectives	
No conflict.	Conflict.
d. Transient related stress	
Little or none.	Overstressed.

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6. Level of Morale/Motivation

	Good	Poor
a. Status of operators	Treated as professionals.	Treated as laborers.
b. Career structure	Operators can find best level in organization.	Peter Principle operates.
c. Physical/mental well being	Operators physically and mentally capable of performing job.	Job performance adversely affected by physical and/or mental impairment.

7. Competence of Operators

	High	Low
a. Training	Operators generally well trained in emergency procedures.	Operators poorly trained in emergency procedures.
b. Certification	Peer review is used.	No peer review is used.
c. Performance feedback	Operators given periodic feedback on performance.	Operators given no feedback on performance.
d. Experience	Operators experienced in dealing with target event.	Operators not experienced in dealing with target event.

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resulting unconditional probabilities (frequencies) of operator successes are summarized below.

E.3.1. Operator Controls Repressurization

Following the practice session, the first operator action from Table E.1 to be addressed was 1b, for which the following initial conditions were set:

(a) The steam-line break consisted of a 1-ft^2 hole.

(b) The reactor was at full power.

(c) The break was outside the containment vessel.

A definition of the target event was at first rather elusive. Starting with the operator recognizing that a steam-line break had occurred, the group considered several intermediate actions before arriving at the following:

> Operator throttles charging pumps after primary pressure reaches high-pressure safety injection (HPSI) head. (Corresponds to Step 8 of Calvert Cliffs emergency operations procedures for a steam-line break.)

This was considered the event which would determine whether or not the operator would successfully control the repressurization. In arriving at

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their prediction, the group followed the 10 steps outlined in Section D.4 of Appendix D. As noted there, the final step involves sensitivity analyses to determine ranges of disagreement, if any exist.

Discussion of the input assessments took about four hours, with considerable disagreement expressed for over one-half of the assessments. Finally, a set of assessments was agreed upon as a base case, and this yielded a probability of success for the target event of 0.974. When the contentious assessments were replaced by the most pessimistic values, the target success probability dropped to 0.867. When they were replaced by the most optimistic assessments, the success probability rose to 0.992. These two values were taken as the minus (-) and plus (+) uncertainty values, respectively; however, in fairness, it should be said that during these sensitivity analyses no individual in the group believed all of the pessimistic or all of the optimistic assessments. Thus, the agreed-upon range of success probability from 0.867 to 0.992 considerably exceeds the range that would have been obtained if each individual's assessments had been tried in the influence diagram. Looked at differently, the range of the failure rate, 0.008 to 0.133, is little more than 15 to 1, which is considerably less than the factors of 100 or even 1000 that occasionally characterize the uncertainty in failure rates obtained by other methods.

The 0.026 failure frequency (1 - 0.974) was attributed both to personal factors and to the quality of information available to the operator (control room design and procedures). The quality of information was considered to be the factor which could be improved most easily. Specifically, the importance of this operator action could be better defined in the procedures and a P/T CRT plot with the acceptable ranges of operation marked would greatly improve the quality of information.

Additional sensitivity analyses were performed to see what the effect would be of improving the Calvert Cliffs design and procedures. This can be simulated in the influence diagram (see Appendix D) by moving the weights of evidence to 100 on both these influences. When that is done, the probability of success rises to 0.986. A minimally licenseable plant was also simulated by assigning 0 to both design and procedures, with the resulting probability of success dropping to 0.880.

If all the bottom-level influences are scored at 0, then the probability of success is 0.546. This suggests that the operator in a plant with rather inadequate procedures and design still has better than a 50% change of performing this particular target event successfully. Similarly, in the maximally feasible plant that would be characterized by a score of 100 on all the bottom-level influences, the probability of success moves to 0.992.*

With the completion of the evaluation of operator action 1b, perturbations covering operator actions 1c, 1d, and 1e were considered. Again, the operator was to control repressurization following steam-line breaks as described in Table E.1. Although many of the influence weighting factors changed from those used for operator action 1b, the changes were conflicting with respect to the final success and failure frequencies. Thus the 0.974 frequency of success and the 0.026 frequency of failure obtained for operator action 1b were assumed to also apply to operator actions 1c-1e.

*The value is not 1.0 due to a perception of undefined influences.

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Operator action 1a differed from operator actions 1b-1e in that it was to be performed following a LOCA rather than a steam-line break. In this case, the success and failure frequencies were evaluated to be 0.968 and 0.032, respectively. The increased failure rate was due almost exclusively to the perception that the information in the LOCA procedures associated with performing this action was less informative than that found in the procedures for steam-line breaks.

E.3.2. Operator Controls Auxiliary Feedwater to Maintain Steam Generator Level (Operator Actions 2a-2d)

Operator actions 2a, 2b, 2c, and 2d required that the operator control auxiliary feedwater (AFW) to maintain the steam generator level following steam-line breaks. These operator actions were considered to be very similar to operator actions 1b, 1c, 1d, and 1e, respectively. Both sets of actions are performed during the same basic time frame and both involve the monitoring of a parameter to ensure that an operational limit is not exceeded. Thus, the failure frequency of 0.026 determined for operator actions 1b-1d was assumed to also be valid for operator actions 2a-2d. However, since the sets of actions were considered to be very similar, it would appear that there is a high coupling between the two actions. That is, success of operator action 1b would imply an increased potential for the success of operator action 2a, while a failure of operator action 1b would imply an increased potential for the failure of operator action 2a. The dependence equations developed in NUREG/CR-1278 (Ref. 1) were used to quantify this coupling. With the high dependency equation, the frequency of failure to control AFW to maintain steam generator level is decreased to

0.013 when repressurization is controlled and to 0.50 when repressurization is not controlled. Thus three separate frequencies were defined dependent upon the following conditions:

(1) Repressurization does not occur - frequency of failure to control AFW = 0.026.

(2) Repressurization occurs and is controlled by the operator - frequency of failure to control AFW = 0.013.

(3) Repressurization occurs and is not controlled by the operator - frequency of failure to control AFW = 0.50.

E.3.3. Operator Isolates PORV that Failed to Close (Operator Actions 3a and 3b)

Operator actions 3a and 3b called for the isolation of a power-operated relief valve (PORV) following its failure to close. For this assessment, PORV openings were placed into two categories: (1) those which result from an inadvertent transfer to the open condition or from an initial high pressure transient and (2) those which result from a failure to control repressurization during pressure recovery following a separate initiating event.

For the first category, the PORV failure to close was treated as the overcooling initiating event, and the probability of isolation was evaluated. The influence diagram evaluation produced success and failure frequencies

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of 0.999 and 0.001, respectively, for isolation within 5 minutes. These values were eventually changed* to 0.99 and 0.01 for isolation within 15 minutes after a review of the evaluation of this operator action revealed that the primary reason for a low failure rate was the operator familiarity of the event as a result of the TMI-2 accident. Every operator has undergone simulation of this event and has been constantly reminded of its symptoms. Thus the high success rate of 0.999 was determined as a result of personal factors (experience and training) dominating over all other factors. In retrospect, we feel that for the present operational time frame, the value of 0.999 success may not be unreasonable. However, since the evaluation was to be performed for up to a 32 effective full power year life of the plant, there is potential time to lose this high familiarity associated with the PORV failure, not just by individual operators but within the training program itself. This is not necessarily bad. It simply means that the relative training associated with a PORV failure will eventually stabilize at a level corresponding to the perceived importance of the event with respect to other potential events. As a result of this perceived phenomenon, the success and failure frequencies were changed to 0.99 and 0.01 respectively. For similar reasons the time frame for response also was changed from 5 minutes to 15 minutes.

For the second category of PORV failure to close, the sequence involved with the initial event must be examined to identify influences which might affect the probability of isolating the PORV. The one important factor identified was that the operator has already failed to control the repressurization. Thus, with respect to operator performance, an abnormal state of operation has already been achieved. This implies that the probability

*These were the only changes made in the original evaluations.

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of isolating the PORV in this second category may be somewhat lower than that calculated for the first category.

The difference was estimated by evaluating the coupling between the two operator actions: (1) isolate PORV, and (2) control repressurization. From this evaluation it was determined that the coupling should not be considered to be high since the PORV failure will reverse the trend of the recovery. That is, both temperature and pressure will start to decrease again, which, along with the display cues associated with the PORV opening and subsequent failure, should attract the attention of the operator to the PORV. Thus, a low coupling factor was assumed, and the category 1 frequencies of operator success and failure in isolating the PORV (0.99 and 0.01, respectively) were reduced to 0.94 and 0.06, respectively, for category 2 events.

In summary, two conditional sets of success and failure probabilities were estimated for the operator action of isolating failed-open PORV. These two sets are defined as follows:

(1) Use 0.99 and 0.01 as the success and failure probabilities when the PORV failure is the overcooling initiating event.

(2) Use 0.94 and 0.06 as the success and failure probabilities when the PORV failure occurs as a result of a failure to control repressurization following a separate initiating event.

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E.3.4. Operator Isolates Stuck-Open ADV Within 30 Minutes (Operator Action 4)

Operator action 4 was the action evaluated during the practice session described in Section E.2 above. Because some of the panel members were still confused about the evaluation process during the practice session, this action was re-evaluated later in the week. The resulting probabilities for success and failure for this event were estimated to be 0.964 and 0.036, respectively, the failures being attributed almost entirely to personal factors.

It should be noted that in the actual PTS risk analysis for Calvert Cliffs Unit 1 no credit was taken for the isolation of the ADV. It was clear from the thermohydraulic analysis that at 30 minutes isolation of a failed open ADV would have an impact only if flow was maintained to the steam generator. Since no dominant risk sequences were identified for this category, the isolation of the ADV was in general determined to be insignificant.

E.3.5. Operator Stops Forced Main Feed after MFIVs Fail to Close on SGIS Following a Steam-line Break (Operator Action 5)

Operator action 5 calls for the operator to stop forced main feed given that the main feed isolation valves (MFIVs) fail to close on steam generator isolation signal (SGIS) following a steam-line break. An evaluation of this action yielded success and failure probabilities of 0.973 and 0.026, respectively. The failures were attributed to minor deficiencies in the quality of information and personal factors. However, as in the case of ADV isolation, credit was not taken for this operator action. At hot 0% power the main feed flow is very small (≤1%) and at full power the risk associated with continued flow to the steam-line break was considered to be very small relative to other events even without operator stoppage of flow. Thus, the analysis was simplified by not taking credit for this operator action.

E.4. Application of STAHR Methodology to a Small-Break LOCA Event Followed by Loop Flow Stagnation

One of the potential PTS sequences is a small-break LOCA event with a loss of natural circulation after the reactor coolant pumps have been tripped. This low flow condition could lead to rapid cooling of the downcomer region and thus is of some concern. A discussion was held, therefore, to identify potential operator actions which could introduce flow into the loops given that the operator recognizes a violation of the PTS relationship. It was determined that the most likely recovery action would be to further reduce pressure by opening a PORV. Thus the potential for performing this action was evaluated.

Since the panel members were not prepared to discuss this action on the level of detail necessary to perform an influence diagram evaluation, a complete analysis was not performed. Instead, each participant was asked to estimate a final success frequency for the action, keeping the lower level influences in mind but not actually evaluating them. The success frequencies estimated were very low. Frequencies of success estimated by seven participants were 0.01, 0.03, 0.05, 0.05, 0.20, 0.70, and 0.75, the last two estimates being made by the operators. The group as a whole felt that the operators might have a better feel for this action, but there was enough skepticism to keep anyone from changing his estimate. Thus, a value of 0.05 was agreed to by the majority of the group. This low value was based primarily on the group's opinion that a complex assimilation of data might be necessary to really identify a need for action; and even upon identification of a need, there might be some reluctance to open a PORV with a small-break LOCA event already in progress.

Even though this frequency of success was obtained from a less rigorous approach than that used for other operator actions, the value was used as a gauge of the likelihood of recovery. Therefore, since the recovery estimate was very low, no credit for recovery was included in the analysis.

E.5. Application of STAHR Methodology to a Reactor Trip Following Loss of Pump Coolant Water Supply

Subsequent to the meeting of the group, several additional operator actions have been identified which might be of interest. These actions were initially evaluated on the basis of their impact on consequence rather than on frequency. With one exception, these operator actions were determined to have little if any effect on the final consequences and thus were ignored. The exception was the operator action which involves tripping the reactor coolant pumps when pump coolant water supply is lost. As stated earlier, failure to trip the pumps when circulating pump coolant water is lost has been assumed to lead to a pump seal failure, i.e., a small-break LOCA. The problem of assigning a frequency of success to this operator action is that the time available to trip the pumps before seal failure occurs cannot be well defined. A 15-minute time frame was chosen for analysis purposes. Various time reliability correlations were examined and a failure frequency of 5×10^{-2} was chosen. This probability represents the least defendable frequency associated with an operator action that has developed in this study. However, a review of the final PTS risk integration (Chapter 6) showed that with a value of 5×10^{-2} the risk contribution of this sequence was small. In fact, it would appear that the frequency of failure to trip the pumps would have to approach 0.5 in order for this sequence to have a measurable contribution to the risk, and this value would definitely appear to be too high.

E.6. Summary Statement

This appendix has described how one relatively small group in a very limited time span was able to learn the principals of the STAHR methodology and to apply it to specified target events. The concensus of the group was that the failure probabilities calculated were reasonable even though they were higher than would have been originally perceived.

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REFERENCES

1. NUREG/CR-1278.