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HUMAN ACTION PERSPECTIVES BASED ON INDIVIDUAL PLANT EXAMINATION RESULTS

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ABSTRACT

This paper provides perspectives on human actions gained from reviewing 76 individual plant examination (IPE) submittals. Human actions found to be important in boiling water reactors (BWRs) and in pressurized water reactors (PWRs) are presented and the events most frequently found important are discussed. Since there are numerous factors that can influence the quantification of human error probabilities (HEPs) and introduce significant variability in the resulting HEPs (which in turn can influence which events are found to be important), the variability in HEPs for similar events across IPEs is examined to assess the extent to which variability in results is due to real versus artifactual differences. Finally, similarities and differences in human action observations across BWRs and PWRs are examined.

I. INTRODUCTION

An important aspect of the individual plant examination (IPE) program, as described in Generic Letter 88-20, is to identify human actions important to prevention and mitigation of severe accidents. In this context, the human reliability analysis (HRA) is expected to be a critical component of the probabilistic risk assessments (PRAs) done for the IPEs. The determination and selection of human actions for incorporation into the event and fault tree models and the quantification of their failure probabilities can have an important impact on the resulting estimates of core damage frequency (CDF). Not surprisingly, results from the submittals indicate not only that human error can be a significant contributor to CDF, but that correct human action can substantially reduce the overall CDF.

This paper summarizes the human actions found important in the IPEs and addresses the degree of variability in the results of the HRAs across the different IPEs. Of particular concern is the degree of variability in the quantification of similar human actions across different plants. This is important because of the potential impact human error probabilities (HEPs) can have on which human actions and accident sequences are found to be important. After discussing the human actions found important for the boiling water reactors (BWRs) and pressurized water reactors (PWRs), some of the potential causes for variability in HRA results will be discussed, followed by examination of the extent to which variability in HEPs across different plants appears reasonable.

It should be noted that in the process of identifying the important human actions from the submittals, it is found that neither the methods used to identify the actions nor their documentation is consistent across the IPEs. For example, some submittals use Fussel-Vesely or similar measures to identify important actions (and report the resulting indices), while others use a sensitivity analysis approach in which all HEPs less than 0.1 are set to 0.1 and the sequences are requantified. Selected human actions are then systematically returned to their original values and reductions in CDF are examined to determine which actions are having the greatest impact. Other submittals determine which human actions are reducing CDF by an order of magnitude and report those as the important human actions. In some cases the percent contribution to core damage is reported, while in others risk achievement worth or risk reduction values are presented. In some instances a list of important human actions is provided, but the basis for the list is not discussed. Nevertheless, most

submittals attempted to provide some indication of which actions are important and the discussion below is based on what is reported in various sections of the IPE submittals.

II. HUMAN ACTIONS GENERALLY FOUND TO BE IMPORTANT FOR BWRs

A list of the most important human actions identified in a review of all 26 BWR IPEs submitted to date is presented in Table 1. The table lists the human action event, the percentage of all BWR IPEs finding the event important, and the percentage of IPEs finding the event to be important as a function of BWR class. Of the 26 submittals reviewed, five are in the BWR 1/2/3 class, 14 are in the BWR 3/4 class, and seven are in the BWR 5/6 class.

Table 1 Important human actions and percentage of BWR IPEs finding the action important.

Important Human Actions	% of All BWR IPEs	% of BWR 1/2/3s	% of BWR 3/4s	% of BWR 5/6s
Manual depressurization	77%	80%	79%	71%
Containment venting	58%	40%	64%	57%
Initiate standby liquid control (SLC)	54%	80%	50%	43%
Align containment or suppression pool cooling	54%	60%	50%	57%
Level control in an anticipated transient without scram (ATWS)	31%	60%	36%	0%
Recover ultimate heat sink	31%	20%	43%	14%
Align/initiate alternate injection	23%	20%	29%	14%
Inhibit automatic depressurization (ADS)	23%	20%	21%	29%
Miscalibration of pressure switches	19%	20%	21%	14%
Initiation of isolation condenser	N/A	80%	N/A	N/A
Control feedwater events (e.g. loss of instrument air)	15%	20%	14%	14%
Manual initiation of core spray or other low-pressure system	12%	20%	21%	0%
Miscalibration of low-pressure core spray permissive	12%	20%	14%	0%
Provide alternate room cooling	12%	0%	7%	29%
Recovery of injection systems	12%	0%	14%	14%

Only a few specific human actions are regularly found to be important across the BWR IPEs. That is, while many different events are indicated as being important, relatively few are important to most of the IPEs. Thus, an attempt was made to group some of the operator actions according to the function to be accomplished. For example, several licensees find events related to aligning an alternate injection source during transients, loss-of-coolant accidents (LOCAs), and station blackouts (SBOs) important. Even though the alternate systems used ranged from firewater to suppression pool cleanup, the function accomplished by performing the action is similar. In order to help capture the general types of events demonstrating importance for BWRs, these actions with similar functions are grouped and are presented in Table 1 along with other important individual operator actions. The events most frequently found to be important are briefly discussed below.

Manual depressurization of the vessel[a] so that low-pressure injection systems can be used after a loss or unavailability of high-pressure injection systems is important in most of the BWR submittals. This action is particularly important in some plants for long-term SBO sequences where depressurization is needed to allow injection from firewater systems, after loss of steam-driven systems such as reactor core isolation cooling (RCIC). This human action is important largely because most plant operators are directed to inhibit automatic actuation of the automatic depressurization system (ADS) by the plant emergency operating procedures (EOPs). Thus, operators must manually depressurize the vessel when injection from low-pressure systems is required to cool the core. The contribution to total CDF by this event ranged from 1 to 44%.

The human action to inhibit ADS is found to be important in the anticipated transient without scram (ATWS) sequences of several submittals. In fact, some licensees assume that because of the instabilities created under low-pressure conditions during an ATWS, core damage will occur if the operators fail to inhibit ADS. Given this position, it is somewhat surprising to find that only 23% of the BWR licensees identify inhibition of ADS as being important. The low percentage is partly due to how an ADS inhibit is modeled. Many licensees assume that failure to perform this action has a very low probability or else they do not model it at all. Other licensees model the failure to inhibit ADS as only resulting in core damage if it occurs in conjunction with a second failure (e.g., failure of standby liquid control (SLC) or failure of low-pressure injection flow control). Such a model can have the effect of reducing the importance of this type of accident sequence and thus the importance of the related human errors. The remaining licensees model the failure to inhibit ADS during an ATWS as resulting directly in core damage. This human error is noted as being important for approximately 50% of the licensees that model an ADS inhibit in any fashion.

Several of the licensees found two other ATWS-related events to be important. Operator action to initiate boron injection during an ATWS is important in 54% of the BWRs and 31% of the licensees identify level control as being important. As with ADS inhibit, the modeling of these events partially affects their importance to core damage. For example, early SLC initiation is modeled by some licensees while others consider both early and late initiation times. The initiation times (important in calculating the HEPs) are based on avoiding adverse conditions such as high suppression pool temperatures and are somewhat variable, ranging from 1 minute up to 45 minutes. Some licensees take credit for alternate means of injecting boron and others take credit for level control as a means of reducing core power to acceptable levels following SLC failure. All these variables can contribute to the importance of the failure to manually initiate SLC. Modeling of level control is highly variable, with several different factors influencing the way it is modeled. Whether these actions are important for particular licensees is to some extent a function of the contribution of the ATWS sequences to overall CDF. The contribution to CDF for these events is usually in the 1 to 3% range.

Human actions related to decay heat removal (DHR) are identified by many licensees as being important. Two of the most frequently identified important actions in BWRs are actions related to DHR sequences in transients and LOCAs. With a loss of the power conversion system (PCS) and safety relief valves (SRVs) open, containment temperature and pressure must be controlled. The actions to provide some form of containment or suppression pool cooling or to vent containment when adequate cooling cannot be provided are important in over 50% of the submittals. Plant characteristics and modeling differences are important factors in determining the impact of these human actions. For example, plants require actuation of DHR before some adverse conditions are reached. These conditions can range from reaching a high suppression pool temperature that results in loss of emergency core cooling system (ECCS) pumps to reaching a high containment pressure that results in closure of SRVs that must remain open to maintain the vessel at low pressure (for

[a]The variability in HEPs for this event across the BWR IPEs is discussed in section IV.

coolant injection from low-pressure systems). However, some licensees do not model the failure of DHR as leading to a failure in the ability to inject water into the vessel from ECCS or from alternate injection systems. In addition, for some licensees (but not others), the steam released following containment failure is identified as having a negative impact on the operability of injection systems. Regarding venting, some licensees do not model it at all. They either do not have reliable venting systems, do not have a strong need to vent, or simply do not take credit for venting. The contribution to CDF for these events generally ranges from 1% to 5%, with one licensee indicating a 12% contribution.

III. HUMAN ACTIONS GENERALLY FOUND TO BE IMPORTANT FOR PWRS

A list of the most important human actions identified in a review of all 50 PWR IPEs submitted to date is presented in Table 2. The table lists the human action event, the percentage of all PWR submittals finding the event important, and the percentage of submittals finding the event to be important as a function of PWR class. The PWRs are separated into five classes: Babcock and Wilcox (B&W) plants, Combustion Engineering (CE) plants, and Westinghouse plants with 2, 3, and 4 loops (i.e., W-2s, W-3s, and W-4s). Of the 50 submittals reviewed, five of the plants are B&Ws, 11 are CEs, four are W-2s, nine are W-3s, and 21 are W-4s.

Table 2 Important human actions, and percentage of PWR submittals finding the action important

Important Human Actions	Percentage of IPEs Finding Event Important (for All PWRs and by PWR Class)					
	All PWRs	B&W	CE	W-2	W-3	W-4
Switchover to recirculation (plants with manual or semi-automatic switchover)	80%	80%	N/A	100%	66%	80%
Feed and bleed	62%	60%	73%	50%	44%	66%
Depressurization/ cooldown	52%	40%	27%	100%	67%	52%
Use of backup cooling water systems	38%	60%	27%	25%	55%	33%
Makeup to tanks for water supply	38%	40%	18%	25%	44%	38%
Restore room cooling	30%	20%	45%	25%	33%	24%
Restore main feed water or condensate to steam generators	28%	40%	27%	25%	33%	24%
Proper control of auxiliary feed water/emergency feed water (AFW/EFW)	28%	40%	36%	25%	0%	33%
Trip reactor coolant pumps (RCPs)	26%	60%	36%	50%	11%	14%

Important Human Actions	Percentage of IPEs Finding Event Important (for All PWRs and by PWR Class)					
	All PWRs	B&W	CE	W-2	W-3	W-4
Pre-initiators	26%	0%	55%	0%	22%	23%
ATWS reactivity control	24%	0%	18%	0%	11%	42%
Water supply for AFW/EFW	16%	0%	45%	25%	11%	5%
Initiation of AFW/EFW	16%	0%	36%	0%	11%	14%

As in the BWRs, only a few human actions are regularly found to be important across the PWR submittals. The human action most consistently found important is the switchover to recirculation during LOCAs. Other human actions frequently found important include feed and bleed, and actions associated with depressurization and cooldown. Only these three actions are found important in more than 50% of the submittals. They are discussed in more detail below, along with several other actions frequently found to be important by the licensees.

Switchover to recirculation on low ECCS level is important for LOCA sequences in most submittals for plants with semi-automatic or manual switchover. All of the 11 CE plants have an automatic switchover, as do 4 of the other plants. For the 35 plants that require operator actions to complete the switchover (either completely manual or semi-automatic), 80% of the submittals find this action to be important. One possible reason some licensees fail to find this action important may be because the sizes of reactor water storage tanks (RWSTs) vary from plant to plant. Those licensees with plants that have larger RWST capacities may model the small LOCA and long-term transient sequences as not requiring a switch to recirculation cooling, thereby lessening the importance of the recirculation function and hence human actions related to recirculation cooling. In addition, some licensees model RWST refill as a preferred action over recirculation cooling, particularly in small LOCA and long-term transient cooling situations. This again lessens the overall importance of recirculation cooling and the corresponding related human actions. For the licensees finding the operator action of switchover to recirculation important (and reporting a contribution to total CDF), the contribution to CDF ranges from less than 1% in several cases to as much as much 16.5%, with an average contribution of 6.4%.

Many licensees identify initiation of the feed-and-bleed operation as important. This event is important in transient and steam generator tube rupture (SGTR) sequences when all feedwater has failed. In addition, a few licensees find the establishment of a reactor coolant system (RCS) bleed path with one power-operated relief valve (PORV) important in small LOCAs. Sixty-two percent of the submittals indicate that feed and bleed is one of the more important events. Why some licensees fail to find feed and bleed important can be due to many interrelated and not easily discernible reasons. For instance, the relative reliability of each plant's AFW\EFW system is a factor since it is only in sequences where AFW\EFW has failed that feed and bleed becomes another important action in the "defense in depth" to providing core cooling. Thus, accident sequences involving AFW\EFW failure (and thus the need to use feed-and-bleed) can vary considerably in frequency, thereby affecting the overall importance of the feed and bleed function. Specific support system dependencies can also be important to the overall reliability of feed and bleed and hence the importance of this human action. For plants with a higher susceptibility of failing feed and bleed due to support system failures, this mode of cooling is less reliable, and so the human action of operating feed and bleed can be less important. In addition, many licensees spent considerable effort in also modeling the ability to depressurize the plant and use condensate as yet another way to achieve core cooling. Taking credit for such action further lessens the overall importance of feed and bleed and the related human action. Other factors related to the success criteria for feed and bleed as well as the HEPs themselves can also contribute to the relative importance of this mode of cooling and the human action. The contribution to CDF for this event ranges from less than 1% to 11%, with most submittals showing relatively small contributions from this event, resulting in an average contribution to total CDF of 3.7%.

More than half of the licensees found the depressurization and cooldown opeation important in order to use available sources of core cooling and in many cases to lessen SGTR leakage. This action usually (but not always) involves depressurizing the steam generators to cooldown the RCS and is found important in all types of sequences except ATWS. It is most frequently important in SGTR sequences. Fifty-two percent of the licensees find the human action important. As discussed above regarding feed and bleed, reasons for failing to find depressurization and cooldown important can be numerous and interrelated, and include the same reasons as those described for the feed-and-bleed event. In addition, not all of the plants even model this mode of cooling -- in some cases because of the relatively low capacity to be able to depressurize in some scenarios, depending on PORV, ADV, or other equipment sizes. The contribution to CDF for this event ranges from less than 1% to 6.7%, and is similar to feed-and-bleed. Most submittals show relatively small contributions from this event, resulting in an average contribution to total CDF of 2.7%.

None of the remaining human actions are found important in more than 38% of the submittals and none of them make consistently large contributions to CDF. As is seen in Table 2, the remaining human actions are not important in a large percentage of the submittals. Recovery and use of backup cooling systems, supplying makeup for injection sources, and recovering room cooling are important for accident sequences in approximately one-third of the submittals. Several actions related to restoration and appropriate use of MFW and AFW systems are found important in several submittals, and tripping the RCPs upon loss of seal cooling is important in about 25% of the submittals. Similar to the BWRs, preinitiator events, including both miscalibration and restoration errors, are found important in some submittals. The miscalibration errors tend to involve traditional instruments such as level, pressure, and temperature sensors and transmitters, but the restoration errors tend to vary across submittals. Examples of important restoration errors include those associated with AFW\EFW systems, diesel generators, and several unique events such as leaving a nitrogen station manual valve closed and failing to remove a jumper in the reactor protection system (RPS) after refueling.

IV. VARIABILITY IN HUMAN ERROR PROBABILITIES

There are numerous factors that can influence the quantification of HEPs and introduce significant variability in the resulting HEPs, even for essentially identical actions. General categories of such factors include plant characteristics, modeling details, sequence-specific attributes (e.g., patterns of successes and failures in a given sequence), dependencies, HRA method and associated performance shaping factors (PSFs) modeled, application of the HRA method (correctness and thoroughness), and the biases of both the analysts performing the HRA and the plant personnel from which selected information and judgments are obtained. Although many of these factors introduce appropriate variability in results (i.e., the derived HEPs reflect "real" as opposed to artifactual differences), it can be seen that several have the potential for causing inappropriate variability.

In order to examine the variability in HRA results from the IPEs and to assess the extent to which variability in results is due to real versus artifactual differences, the HEPs from several of the more important human actions appearing in the submittals were examined across plants. However, since the same general conclusion is reached after examining several important human actions for the BWRs and PWRs, the results from the examination of a single important human action are presented in this summary paper.

The HEPs for failure to depressurize the vessel during transients are presented in Figure 1 for the various BWR submittals. (Values from a given submittal are indicted by an arbitrarily assigned number.) As can be seen from the figure, a relatively large degree of variability exists across the submittals for this event. There appear, however, to be reasonable explanations for much of the variability in the HEPs. For values on the high end of the continuum, the events modeled appear to be special cases of depressurization. For example, the high value for Nine Mile Point 1 (2) involves depressurization using main steam isolation valves (MSIVs) and the condenser, which is apparently not typically modeled. The high value for Peach Bottom 2&3 (16) and the next to the highest value for Limerick 1&2 (18) are for the case when partial and controlled depressurization is needed to allow use of the condensate system. The highest value for Limerick 1&2 (18) is for recovery of a failed automatic depressurization. While the justification for the high values for Big Rock Point (1) is not apparent, it is unique relative to the other BWRs in that it has some characteristics similar to PWRs. The reason for the high value for Cooper (10) is not obvious either, but the large range of values for Cooper (10) is apparently related to the number of SRVs to be used for depressurization.

The explanations for the approximately 1.5 to 2 orders of magnitude difference between the HEP values in the middle range appear to be related, at least in part, to dependencies, and initiator and sequence-specific factors. For several

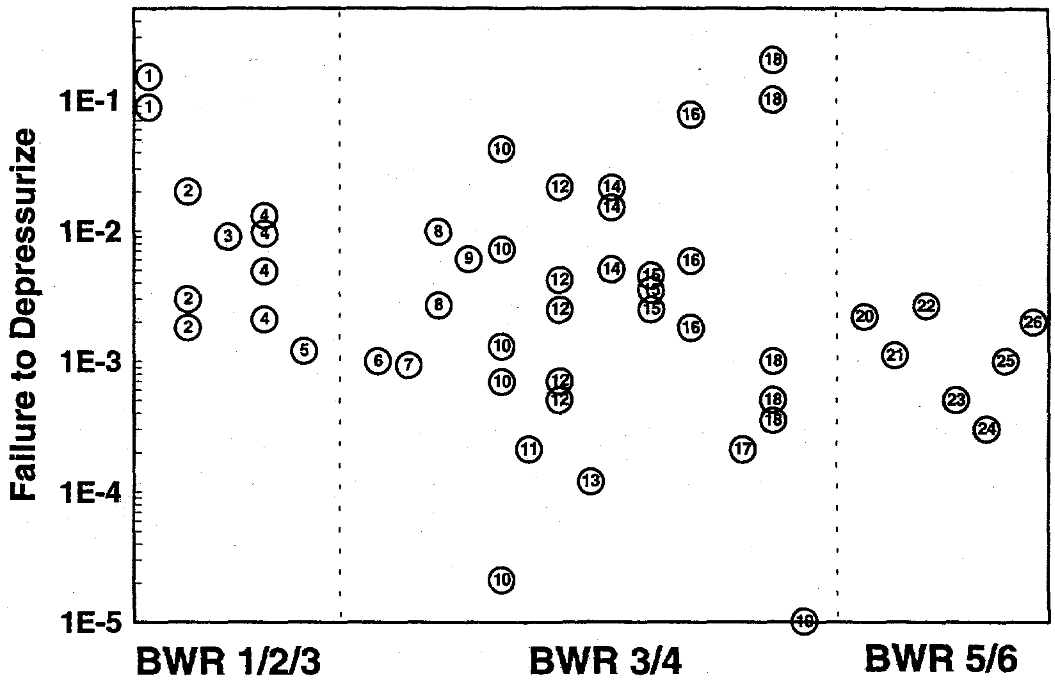

Figure 1 HEPs for failure to depressurize by BWR class

licensees, such as Nine Mile Point 1 (2), Dresden 2&3 (4), Fermi 2 (12), and Limerick 1&2 (18), the licensees conducted relatively detailed analyses and apparently derived multiple values in order to take specific conditions into account. The specific conditions include loss of offsite power (LOSP), SBO, loss of dc power, use of turbine bypass valves for depressurization, and loss of feedwater and standby feedwater. Nevertheless, while much of the variability in the middle range of values is clearly explainable, some of the differences are less clear. For example, the generally lower values for Fermi 2 (12) and Limerick 1&2 (18) relative to those from Nine Mile Point 1 (2) and Dresden 2&3 (4) are not straightforwardly explained, but may very well be due to valid, plant-specific characteristics.

Finally, the reasons for all the relatively low HEP values [i.e., Cooper (10), Duane Arnold (11), Fitzpatrick (13), Vermont Yankee (17), and Susquehanna 1&2 (19)] are not clear. It can be argued that at least the top three or four values from these submittals fall within an acceptable range and it may very well be the case that there are plant-specific characteristics that support the HEPs on the lower end of the continuum. For example, the relatively low value for Cooper is for a long term-DHR sequence where operators have up to 4 hours to depressurize. The lowest value (from Susquehanna (19), is clearly an outlier, but this value is consistent with many of their HEP values and is a direct function of the unique HRA methodology used in the Susquehanna IPE.

The main point to be derived from the examination of the HEPs for specific actions across plants is that although at least some of the variability in HEP values can be an artifact of the way in which HRA methods are applied, it also appears that in many cases there are acceptable reasons for much of the variability in HEPs and in the results of the HRAs across the different IPEs.

V. SIMILARITIES AND DIFFERENCES IN HUMAN ACTION OBSERVATIONS ACROSS BWRs AND PWRs

Given the basic differences between BWRs and PWRs, the preceding discussion has for the most part provided separate observations regarding the submittals for the two different plant types. Nevertheless, there are obvious commonalities across the plant types, which prompt an examination of potential similarities or differences in the operational and HRA-related observations. Several observations follow.

- Neither BWR nor PWR submittals show a broad range of consistency in terms of which human actions are found important. Given the numerous factors that can influence the results of the IPEs, and the fact that redundancy of function creates the opportunity for quite a few operator actions to be taken to mitigate an accident scenario in both BWRs and PWRs, there is no reason to expect more consistency in what is found to be important for one type of plant as opposed to the other.

- Of the events frequently found important in BWRs and PWRs, the only similar actions are those related to depressurization and cooldown.

- Events related to aligning or recovering backup cooling water systems (e.g., service water) are found important in approximately one-third of both the BWRs and PWRs.

- In both BWRs and PWRs, no individual human action appears to account for a large percentage of the total CDFs across multiple submittals. Taken together, however, human actions are clearly shown to be important contributors to operational safety.

In summary, it seems that most of the differences in the HRA results of the BWR and PWR submittals are related (not surprisingly) to the differences in the systems of the two types of plants. In terms of more methodological aspects, general patterns of results, and overall importance of humans in operating the plants, the BWRs and PWRs are reasonably similar.

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