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Sensitivity Analysis of HEPs in the ABWR PRA

A sensitivity analysis has been conducted of the human error probabilities in the Level I ABWR PRA. The first step in the sensitivity analysis process was to identify and list in rank of importance all human errors included in the Level I PRA. That listing is shown in the attached Tables 1 and 2. Two additional recovery items involving operator action are recovery of offsite power and recovery of diesel generators. Those two items are not included in this sensitivity analysis since the failure probabilities for those items were determined from actual data, not from human reliability analysis, and include factors other than human actions.

The 12 HEPs in Table 1 are the only HEPs that show-up in the top 300 cutsets of the analysis, representing 98% of the total core damage frequency. The fourth column in the table gives the HEP value used in the PRA. The fifth column is the error factor (the ratio of the 95th to 50th percentile of the uncertainty distribution) on the HEP, as provided by the PRA uncertainty analysis. In cases where there was no clear basis for determining an error factor, a value of 15 was used.

The sixth column is the Fussell-Vesely Importance, which is a measure of the percentage contribution of each item to the total CDF. The items in the table are ranked according to decreasing F.V. The last column is the Risk Achievement Worth, which is another importance measure, and is the factor by which the total CDF would be multiplied if that specific item had a failure probability of 1.0.

All items below #5 (HBMAER1) contribute much less than 1%, individually, to total CDF. Most of the items in Table 1, plus CALN002, HFE008CF, and HPR007CF from Table 2 have a relatively high R.A.W., often because these items have relatively low assigned failure probabilities. All items on the list except the 15 items identified above have very low F.V. and R.A.W. measures, and are eliminated from further consideration.

The first screening analysis was made by doubling all the failure probabilities (simultaneously) of all of the 15 items identified above, and then reevaluating core damage frequency. The resulting CDF was 58.94% higher than the base CDF. This result provided an indication that the CDF was fairly sensitive to one or more of the 15 items.

The next sensitivity run was made by increasing the failure probability of each of the 15 items, individually, by a factor of 4. The factor of 4 includes the 95th percentile of the uncertainty distribution. The results are shown in Table 3. The top 5 items each resulted in increases in CDF greater than 1%. The 6th and lower-ranked items each resulted in increases of less than 1/2%, which is considered to be insignificant.

An additional analysis was made, in which the failure probabilities of the 10 items below #5 were increased (simultaneously) by a factor of 4.

The result was a 2.33% increase in total core damage frequency, providing a further indication of the relative insensitivity of CDF to variability of the failure probability of these 10 items.

Because of the general uncertainty in theoretical human error analysis, and the involved and labor-intensive nature of the various HRA procedures, the ABWR PRA uses screening methods wherever possible. Even though the HEPs used in the ABWR PRA are screening values and are conservative, no sensitivity runs were made with failure probabilities decreased from the values used in the PRA. The use of more realistic HEPs would reduce total CDF by a small amount, but would require additional more-detailed HRA. Use of more realistic HEPs might also change the relative importance and sensitivity of the individual HEPs, but it is doubtful that any basic conclusions or recommendations would change.

The top 5 items are identified as the most sensitive HEPs in the PRA. The top 4 items are operator actions that are needed after the accident sequence is initiated (Type C actions). Each of the operator actions represented by HEPs #1-#4 requires the following:

1. The operator must have a clear unambiguous indication of the conditions requiring the action.

2. The operator must have the capability of performing the necessary action from the main control room in a simple straightforward manner.

3. The operator must have clear written operating procedures regarding the action to be taken.

4. The operator must have thorough simulator training in the conditions requiring the action.

HEP #5 represents a Type A action (occurs prior to initiation of the accident sequence). This error may be an error of omission or an error of commission. To prevent this error from occurring, administrative controls must be in place to require independent verification of the valve position following maintenance, positive control of the key to the valve lock during periods when entry to the containment is possible, and control room verification of the valve position prior to startup.

Discussions of the derivation of the failure probabilities for the five most sensitive actions follow.

All five of the important operator actions relate to makeup of reactor inventory - four with the reactor at high pressure, and one (COND) with the reactor at low(er) pressure. One of the items (HOOBOPHL) is an operator action to backup automatic signals that failed to initiate HPCF. Three of the items (Q, Q2, and COND) are actions for recovery of (non-safety) systems that were in normal operation and were lost (tripped) at the time of the event. In cases where failure of the system was the cause of (initiated) the event, no credit was given to the operator for recovery of the system. In some instances, this is a very conservative treatment. The remaining item (HBMAER1) is a Type A operator action resulting in mispositioning of a valve on the HPCF B discharge line.

HOOBOPHL - Failure to Manually Initiate HPCF.

HPCF is automatically initiated if reactor water level decreases to Level 2. The PRA gives credit to the operator for manual backup of the automatic signal. The value used for the probability of failing to provide manual backup initiation is 0.1. (This value for manual backup actions is used throughout the PRA wherever the action required is simple and performed from the control room.)

The action required to manually start the HPCS pumps is simple and is performed directly from the control room with minimal time required for performance of the action. The operator has direct (hardwire) control for initiation of HPCF B. Manual initiation of HPCF C is transmitted through multiplex equipment. Operator action for initiation of HPCF B and C is modeled as a single action. The time available to the operator for cognition and performance of the backup action is at least 30 minutes, except for the ATWS and large LOCA events, where the events proceed more rapidly. For those events, the initiating frequency is low, and the backup manual initiation of HPCF has little effect on CDF.

The estimate of 10% for operator failure probability is made based on a long trail back through GESSAR, the Limerick PRA, Swain and Guttman (NUREG/CR-1278) and even WASH-1400 (see Table G-1 on p.G-4 of August, 1983 issue of NUREG/CR-1278). In Figures 7-1 and 8-1 of NUREG/CR-4772 (February, 1987) curves for suggested screening values and nominal values for diagnosis HEPs are given. In the case of the ABWR backup manual initiation of HPCF, the operator has at least 30 minutes available, and the actual operation of starting the pumps (after recognition of the need) is simple and requires a minimal amount of time. With at least 30 minutes available for diagnosis, the curves of Figures 7-1 and 8-1 of NUREG/CR-4772 suggest a failure probability of 0.01. The ABWR PRA uses a conservative screening value of 0.1.

Q - Failure to Inject with Feedwater During a Non-Isolation Event.

The ABWR feedwater controller is designed to withstand turbine trips (and other transients) without tripping. Nevertheless, the PRA analysis assumed (conservatively) that 50% of the non-isolation initiating events would result in tripping of the feedwater pumps. It was further postulated that in 10% of these cases, the operator would fail to restart feedwater pumps. (This also is probably conservative, since the FW pumps were in operation just prior to the incident, and only one pump is needed in the accident sequences.)

As in the case of backup initiation of HPCF, the estimate of operator failure probability is made based on GESSAR, the Limerick PRA, and Swain and Guttman (NUREG/CR-1278). The same curves in Figures 7-1 and 8-1 of NUREG/CR-4772 (February, 1987) for suggested screening values and nominal values for diagnosis HEPs were used. In all cases of FW recovery in the ABWR PRA, the operator has at least 30 minutes available, and the actual operation of restarting a FW pump (after recognition of the need) requires a minimal amount of time. With at least 30 minutes available for diagnosis, the curves of Figures 7-1 and 8-1 of NUREG/CR-4772 suggest a failure probability of 0.01. The value of 0.1 used in the ABWR PRA is conservative, - even more conservative than the value used for initiation of HPCF, because of the higher frequency of, and greater operator familiarity with, startup of feedwater pumps.

Initiation and control of feedwater and condensate are basic, routine actions which are performed by the operator repeatedly, from the control room, and under a wide spectrum of varying circumstances and conditions. There are few, if any, actions more familiar to the operator. However, it is essential that the operator have clear indications of the plant conditions (particularly reactor water level and status of ECCS pumps), that he be thoroughly trained under conditions simulating the spectrum of accident sequences of concern, and that the plant EOPs provide clear instructions.

<u>Q2 - Failure to Inject with Feedwater During an Isolation Event</u>

The analysis in the ABWR PRA assumes that 40% of isolation initiating events will be due to loss of feedwater. This is based on operating data from BWRs in the U.S. For events that are initiated by loss of feedwater, the PRA gives no credit for recovery. This is conservative treatment, since many loss-of-feedwater events (in operating plants) are due to spurious trips which are routinely reset.

The ABWR PRA assumes that 60% of the isolation initiating events will be due to closure of the MSIVs. The ABWR feedwater controller is designed to ride-through a MSIV closure event without tripping. Even so, as in the case of non-isolation events, the ABWR PRA analysis assumes that 50% of the MSIV closure events will result in trip of the feedwater pumps. Also, as in the case of the non-isolation events, the probability of failure of the operator to recover feedwater is assigned a value of 0.1 in the PRA In this case, the operator must first reopen the MSIVs. It is essential that the operator have the means of reopening the MSIVs from the control room, and have clear instructions to do so in the event of falling water level and failure of ECCS pumps to start. It is also necessary that the operator have training in a wide spectrum of events that require him to reopen the MSIVs.

Based on the above factors, the value for Q2 is 0.43 [0.4 + (0.6 * 0.5 * 0.1)].

COND - Failure to Inject with Condensate (to a Depressurized Reactor)

In the PRA analysis, for transient events with successful scram, and for the small LOCA event, credit is given for operator recovery of condensate following failure of high pressure injection and depressurization of the reactor on low water level. Actually, in most cases no operator action is required, since condensate pumps will continue to operate and pump through minimum bypass lines so long as power and suction water are available. If MSIVs close, operator action may be needed to reopen MSIVs, initiate makeup to the condenser hotwell, or start mechanical vacuum pumps. Since the hotwell has a very large supply of water, these actions, that are needed to maintain suction to the pumps, are very long-term actions. Plant administrative procedures should also require that the valve position be independently verified following maintenance. The value of 0.1 used for the probability of failure to recover condensate is a very conservative screening value.

HBMAER1 - Valve E22-F005B Closed (NOFC)

Valve E22-F005B is a normally-open valve on the discharge of the B-loop HPCF pump. This valve is a manual locked-open valve located inside of the drywell, and the valve position is indicated in the main control room. The PRA assigns a probability of 0.01 to the possibility of the valve being closed, due to human error. Since the valve is inside the containment and is a manual locked-open valve, the human error must be Type A (pre-accident). NUREG/CR-4772 (ASEP) suggests use of a basic HEP of 0.03 for pre-accident errors, which it considers conservative. The ASEP and Table 20-22 of the August, 1983 version of NUREG/CR-1278 suggest application of a factor of 0.1 for recovery. Because of the valve lock and the control room indication of the valve position, application of the recovery factor is reasonable. The value of 0.01 used in the PRA is conservative.

HCMAER1, which is the operator error for mispositioning the HPCF C discharge valve, also has a HEP value of 0.01 in the PRA; however, it is much less sensitive than HBMAER1. This is because there is no hardwire backup for manual initiation of HPCF C.

Table 4 gives a list of human action acronyms that have been deleted from an earlier issue of the PRA. The reasons are given in the table.

Table 1 - Human Actions in the Top 300 Cutsets (98.0% of CDF)

RANK	NAME	DESCRIPTION	ASSIGNED PROB.	E.F.	IMPORTANCE F.V. (%)	IMPORTANCE R.A.W.
1.	HOOBOPHL	Failure to manually initiate HPCF (Incl. hardwire backup for EMUX failure - HPCF B)	0.10	5	16.0	2.44
2.	Q	Failure to inject with feedwater	0.05	5	12.5	3.37
3.	Q2	Failure to inject with feedwater(TIS)	0.43	5	10.9	1.14
4.	COND	Failure to inject with condensate	0.10	15	1.85	1.17
5.	HBMAER1	Valve E22-F005B closed (NOFC)	0.01	5	1.72	2.71
6.	ROERROR4	Oper. fails to attempt manual vlv. op. (Backup for RCIC disch. vlv. (F013)	0.10	5	0.15	1.01
7	CTGMANSW	CTG manual disconnect switch [left] open (Following maintenance on gas turbine gen.)	3E-3	3	0.07	1.24
8	RECVRII	Recovery event for Class II sequences (Oper. fails to initiate firewater inj.(0.1))	1E-4	15	0.07	8.08
9.	RPR005CF	Sensor miscalibration	5E-5	10	0.05	11.8
10.	RFL007CF	Sensor miscalibration	5E-5	10	0.05	11.8
11.	HFELEBHX	Water level 8 sensors miscal. (4 div.)	2E-5	10	0.05	25.8
12.	RHRSPER	Oper. fails to manually initiate (SP cooling initiation (within 20 hours))	6E-5	10	0.02	4.09

Table 2 - Human Actions Below the Top 300 Cutsets (2.0% of CDF)

NAME	DESCRIPTION	ASSIGNED PROB.	E.F.	IMPORTANCE F.V. (%)	IMPORTANCE R.A.W.
CALN002A	Miscal. of flow xmtrs FT008A,B & C	5E-5	10	0.14	28.2
RHRCFER	Oper. fails to manually initiate (Backup for RHR core flood A/B/C)	0.10	5	0.06	1.01
HCMAER1	Valve E22-F005C mispositioned (NOFC)	0.01	5	0.05	1.05
ROERROR3	Oper. fails to manually open valve	0.01	5	0.04	1.00
ADSMAN	Failure of ADS manual init. (backup)	2E-3	5	0.01	1.06
ROOIOPHL	Oper. fails to initiate within 30 min. (Backup for RCIC)	0.10	5	<.01	1.00
NHR	Failure to restore normal heat removal	0.01	15	<.01	1.00
RWCU	Failure to actuate RWCU	0.10	5	<.01	1.00
RSTTCOPF	Operator fails to reset trip circuit (RCIC internal trips)	0.01	5	<.01	1.00
SLC000SA	Boron concentration sampling failure	2E-5	10	<.01	1.07
SLC001HE	Operator fails to initiate SLC	0.01	10	<.01	1.00
SLC002HE	Operator fails to initiate SLC tank heater	2E-3	5	<.01	1.00
WOPERR	Oper. fails to perform indicated action (Backup to RBCW initiation)	0.01	5	*	*
HUERROR5	Oper. fails to transfer from CST to SP	0.01	5	*	*
VOPERRF	Operator fails to start pump	1E-3	5	*	*
ASECSNA	Operator fails to backup N2 initiation	0.10	5	*	*

*Below the cutset cutoff level (E-13)

Table 2 - Human Actions Below the Top 300 Cutsets (2.0% of CDF)
(continued)

NAME	DESCRIPTION	ASSIGNED PROB.	E.F.	IMPORTANCE F.V. (%)	IMPORTANCE R.A.W.
CMAW	Operator fails to backup ARI initiation	0.10	5	*	*
	Electrical				
EHU69C	Operator fails to transfer power	1E-3	10	<.01	1.06
EHUB1	Operator fails to bypass	1E-3	10	*	*
EHUB2	Operator fails to bypass	1E-3	10	*	*
EHUB3	Operator fails to bypass	1E-3	10	*	*
EHUB4	Operator fails to bypass	1E-3	10	*	*
EHUS1AD	Oper. fails to xfer stdby charger to Div.I	1E-3	10	*	*
EHUS1BD	Oper. fails to xfer stdby charger to Div.II	1E-3	10	*	*
EHUS1CD	Oper. fails to xfer stdby charger to Div.III	1E-3	10	*	*
EHUS1DD	Oper. fails to xfer stdby charger to Div.IV	1E-3	10	*	*
	Miscalibrations:				
HFE008CF	Miscal. of flow xmtrs	5E-5	10	0.01	3.45
HPR007CF	Miscal. of pressure xmtrs.	5E-5	10	0.01	3.45
AHPT006	Miscal. of pressure xmtrs.	2E-5	10	*	*
RFE635HX	Miscal. of CST level sensors	2E-5	10	*	*
REOSSMSC	Elec. overspeed sensor miscal.	5E-5	10	<.01	1.11
RPR309MC	High turbine exh. press. xmtr. miscal.	5E-5	10	<.01	1.11
RMOSSMSC	Mech. overspeed sensor miscal.	5E-5	10	<.01	1.11
RPR303MC	Low suction press. xmtr. miscal.	5E-5	10	<.01	1.11
	Valve Mispositions:				
ROERROR5	Valve F0[illegible] inadvertently left open	0.01	3	*	*
HBMAER2	Test valve E22-F009B inadvert. left open	0.01	5	*	*
HCMAER2	Test valve E22-F009C inadvert. left open	0.01	5	*	*
C001AMOV	Manual override fails initiation signal	1.8E-4	10	*	*
C001BMOV	Manual override fails initiation signal	1.8E-4	10	*	*
C001CMOV	Manual override fails initiation signal	1.8E-4	10	*	*

*Below the cutset cutoff level (E-13)

Table 3 - CDF Increase With ABWR PRA HRAs Multiplied by 4 (Individually)

RANK	NAME	DESCRIPTION	NEW PROB.	E.F.	CDF INCREASE (%)
1.	HOOBOPML	Failure to manually initiate HPCF (Incl. hardwire backup for EMUX failure - HPCF B)	0.40	5	47.9
2.	Q	Failure to inject with feedwater	0.20	5	37.3
3.	COND	Failure to inject with condensate	0.40	15	5.39
4.	HBMAER1	Valve E22-F005B closed (NOFC)	0.04	5	4.98
5.	Q2	Failure to inject with feedwater(TIS)	0.52	5	2.28
6.	ROERROR4	Oper. fails to attempt manual vlv. op. (Backup for RCIC disch. vlv. (F013))	0.40	5	0.44
7.	CALN002A	Miscal. of flow xmtrs FT008A,B, & C	2E-4	10	0.41
8.	CTGMANSW	CTG manual disconnect switch [left] open (Following maintenance on gas turbine gen.)	2E-4	3	0.21
9.	RECVRII	Recovery event for Class II sequences (Oper. fails to initiate firewater inj.(0.1))	4E-4	15	0.21
10.	RPR005CF	Sensor miscalibration	2E-4	10	0.16
11.	RFL007CF	Sensor miscalibration	2E-4	10	0.16
12.	HFELEBHX	Water level 8 sensors miscal. (4 div.)	8E-5	10	0.15
13.	RHRSPER	Oper. fails to manually initiate (SP cooling initiation (within 20 hours))	2.4E-4	10	0.06
14.	HFE008CF	Miscal. of flow xmtrs.	2E-4	10	0.04
15.	HPR007CF	Miscal. of pressure xmtrs.	5E-5	10	0.04

Table 4 - Human Action Acronyms Deleted from the Model

NAME	DESCRIPTION
PA	Operator fails to inhibit ADS with an ATWS (ADS inhibit now automatic)
ROERROR7	Valve F059 inadvertently left open (Renamed ROERROR5)
HBMAER3	Manual valve F016B inadvertently left open (Renamed HBMAER2)
HCMAER3	Manual valve F016C inadvertently left open (Renamed HCMAER2)
HFL301CF	Miscalibration of flow transmitter (Renamed HFE008CF)
HOOCOPHL	Operator fails to attempt manual initiation within 30 min. (Renamed HOOBOPHL)
HPR305CF	Miscalibration of pressure transmitter (Renamed HPR007CF)
C001AMOP	Failure to manually initiate within 30 min. (Renamed RHRCFER)
AOPINHB	Operator improperly inhibits ADS (HEP deleted - error of commission)
AHPT303B	Miscalibration of pressure transmitters (Renamed AHPT006)