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Sensitivity Analysis for Effect of Uncertainty Factors and Mobile Equipment on Level 2 PSA

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1. Introduction

Not only the occurrence of a major accident, but also the actions of the operator and the proper functioning of the system involve a lot of uncertainty, and this uncertainty greatly affects the quantification of top event [1].

In this study, sensitivity analysis was performed on top event of a Decomposition Event Trees (DET) that are expected to have a significant impact on the results, such as those with uncertainties or those that are highly sensitive to changes in the probability distribution, such as radiation releases from a source, to identify changes in quantification results due to changes in branch probabilities. Additionally, sensitivity analysis was performed for the case where a mobile equipment was added. The ultimate goal is to evaluate the impact of uncertainty in top event and mobile equipment on the Probabilistic Safety Assessment(PSA) results [2].

2. Methods

2.1 Containment Event Tree

In this study, sensitivity analysis was conducted on OPR1000.

The reference Containment Event Tree (CET) consisted of 10 heading [3].

-CONBYPASS: Containment Bypass Accident
-CONISOLAT: Containment Isolation Failure
-RCSFAIL: Reactor Coolant System Status
-MELTSTOP: Core Melt Arrested
-CR-EJECT: Amount of Corium Eject Out of Cavity
-CF-EARLY: Early Containment Failure
-CS-LATE: Status of Late Containment Spray System
-CF-LATE: Late Containment Failure
-BMT-MELT: Containment Basement Melt Through
-SCRUB: Status of Fission Product Scrubbing

2.2 Sensitivity analysis methods and variable selection

Sensitivity analysis is performed to study the changes in the results with respect to changes in the input values.

In this study, sensitivity analysis was performed by changing the branch probability values of DET. Although the branch probability values were varied between 0 and 1, for some heading, the probability was increased or decreased by a multiple.

Sensitivity analysis was also performed for the case of adding mobile equipment, as mobile equipment could be considered as a severe accident management strategy [4].

The variables selected were mostly heading in DET of CET that have probability branch values [3].

-RCSFAIL: Mode of Induced Primary System Failure
-MELTSTOP: Debris Cooled in Vessel No Vessel Rupture
-CR-EJECT: Amount of Corium Ejected out of Cavity
-EVSE: Ex-Vessel Steam Explosion
-H2-MASS: Amount of Hydrogen Produced In-Vessel
-RUPTURE: Peak Pressure to Rupture
-CS-DEBRIS: Excessive Debris in Sump Causes Spray Failure
-EARLY-BURN: H2 Burn Occurred Before RV Rupture
-LATE-BURN: Late Hydrogen Burn
-DB-DEPTH: Depth of Debris Pool
-EXVCOOL: Debris Coolability in Reactor Cavity
-BMT-MELT: : Containment Basement Melt Through

2.3 Sensitivity analysis of Decomposition Event Trees

Table Ⅰ shows the variation in branch probabilities of variables. 'Group' is representing cases with the same branch, but with different probabilities due to the influence of preceding events within the DET.

Table I: Changes in Probability Values by Case

CASE	BRANCH	BASE	S1	S2	S3
RCSFAIL Group A	NO RCS FAIL	0.89	1.0	0.29	0.8
	HOT LEG BREAK	0.1	0.0	0.7	0.1
	SGTR	0.01	0.0	0.01	0.1
RCSFAIL Group B	NO RCS FAIL	0.48	1.0	0.03	0.3
	HOT LEG BREAK	0.5	0.0	0.95	0.5
	SGTR	0.02	0.0	0.02	0.2

CASE	BRANCH	BASE	S4	S5	S6	S7
MELTSTOP Group A	MELTSTOP	0.95	1.0	0.0		
	RV RUPTURE	0.05	0.0	1.0		
MELTSTOP Group B	CTMNT FAIL	0.95			1.0	0.0
	RV RUPTURE	0.05			0.0	1.0
MELTSTOP Group C	MELTSTOP	0.9	1.0	0.0		
	RV RUPTURE	0.1	0.0	1.0		
MELTSTOP Group D	CTMNT FAIL	0.9			1.0	0.0
	RV RUPTURE	0.1			0.0	1.0

CASE	BRANCH	BASE	S8	S9	S10
CR-EJECT	HIGH	0.6	1.0	0.0	0.0
	MEDIUM	0.3	0.0	1.0	0.0

	LOW	0.1	0.0	0.0	1.0

CASE	BRANCH	BASE	S11	S12
EVSE	NO	0.995	1.0	0.95
	YES	0.005	0.0	0.05
CASE	BRANCH	BASE	S13	S14
H2-MASS	HIGH	0.5	1.0	0.0
	LOW	0.5	0.0	1.0
CASE	BRANCH	BASE	S15	S16
RUPTURE	-	133.4 psia	120.1psia	146.7 psia
CASE	BRANCH	BASE	S17	S18
CS-DEBRIS	YES	0.01	0.1	0.0
	NO	0.99	0.9	1.0
CASE	BRANCH	BASE	S19	S20
EARLY-BURN	BURN	0.5	1.0	0.0
	NO BYRN	0.5	0.0	1.0
CASE	BRANCH	BASE	S21	S22
LATE-BURN	YES	0.1	1.0	0.0
	NO	0.9	0.0	1.0
CASE	BRANCH	BASE	S23	S24
DB-DEPTH Group A	VERY SHALLOW	0.9	0.99	0.8
	SHALLOW	0.1	0.01	0.2
DB-DEPTH Group B	SHALLOW	0.9	0.99	0.8
	DEEP	0.1	0.01	0.2
DB-DEPTH Group B	SHALLOW	0.8	0.9	0.6
	DEEP	0.2	0.1	0.4
CASE	BRANCH	BASE	S25	S26
EXVCOOL Group A	COOLED	0.9	0.99	0.8
	NOT COOLED	0.1	0.01	0.2
EXVCOOL Group B	COOLED	0.5	0.9	0.1
	NOT COOLED	0.5	0.1	0.9
EXVCOOL Group C	COOLED	0.5	0.9	0.1
	NOT COOLED	0.5	0.1	0.9
CASE	BRANCH	BASE	S27	S28
BMT-MELT Group A	INTACT	0.95	0.99	0.8
	MELTTHROU	0.05	0.01	0.2
BMT-MELT Group B	INTACT	0.95	0.99	0.8
	MELTTHROU	0.05	0.01	0.2
BMT-MELT Group C	INTACT	0.9	0.95	0.7
	MELTTHROU	0.1	0.05	0.3
BMT-MELT Group D	INTACT	0.95	0.99	0.8
	MELTTHROU	0.05	0.01	0.2
BMT-MELT Group E	INTACT	0.75	0.9	0.5
	MELTTHROU	0.25	0.1	0.5
BMT-MELT Group F	INTACT	0.6	0.9	0.2
	MELTTHROU	0.4	0.1	0.8

In this study, mobile equipment considered were the '1MW mobile power generation vehicle' and a 'low-pressure mobile pump truck'.

The initial events where the mobile equipment is applied are 'station blackout accidents caused by failure during emergency diesel generator operation' and 'station blackout accidents caused by failure to start emergency diesel generators.'

3. Results and Discussion

Fig. 1 represents the results of sensitivity analysis on branch probability.

According to the analysis, the most influential factor for Early Containment Failure (ECF) is 'EVSE'. In the case of S12, which increased the probability of containment building damage, the fraction of ECF increased by 0.4%.

For Late Containment Failure (LCF), the influential factors are "SGTR" and "LATE-BURN". In the case of S3, which increased the probability of Temperature Induced Steam Generate Tube Rupture(TI-SGTR), the fraction of LCF decreased by 0.4%. In the case of S21, which increased the possibility of hydrogen burn, the fraction of LCF increased by 0.8%.

For Basement Melt Through (BMT), the influential factors are "MELTSTOP" and "EXVCOOL". In the case of S5, when the branch probability of MELTSTOP is changed to 0, the fraction of BMT increased by 0.7%. In the case of S27 or S25, which decreased the probability of BMT when debris is not cooled or increased the probability of debris cooling, the fraction of BMT decreased by 0.2% each.

The most influential factor for containment building bypass (BYPASS) is "SGTR". In the case of S3, which increased the probability of TI-SGTR, the fraction of BYPASS increased by 12.5%.

The addition mobile equipment reduces the frequency of containment building damage, with a significant decrease in the fraction of LCF. It is shown in Table II.

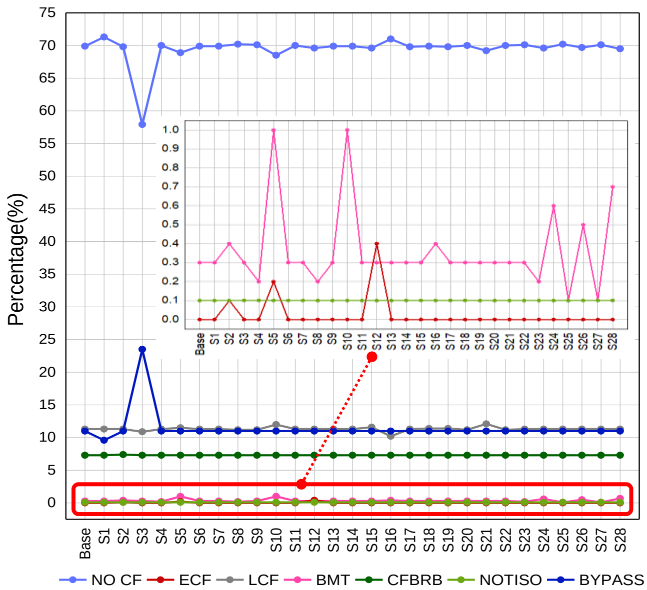

Fig. 1. Results of Sensitivity Analysis

Table II: Results of Added Mobile Equipment

Containment Failure Mode		Base		Add Mobile Equipment	
		Frequency (/RY)	Percentage (%)	Frequency (/RY)	Percentage (%)
NO CF		3.419E-06	69.9	3.189E-06	71.0
CF	ECF	2.039E-09	<0.1	1.755E-09	<0.1
	LCF	5.526E-07	11.3	3.925E-07	8.7
	BMT	1.562E-08	0.3	1.354E-08	0.3
	CFBRB	3.586E-07	7.3	3.591E-07	8.0
	NOT ISO.	2.569E-09	<0.1	1.577E-09	0.0
	BYPASS	5.393E-07	11.0	5.328E-07	11.9
	Total of CF	1.471E-06	30.1	1.301E-06	29.0
LERF		5.439E-07	11.1	5.361E-07	11.9
Total		4.890E-06	100.0	4.490E-06	100.0

4. Conclusions

There is a lot of uncertainty involved in conducting Level 2 PSA, which can have a significant impact on the quantification of results. Therefore, sensitivity analysis was performed on the top events of DET to address this uncertainty. The results of the analysis showed that TI-SGTR was sensitive to changes and responded significantly. Additionally, it was found that the addition of mobile equipment had a positive impact on LCF.

In future research, we plan to discuss the probability branch values of TI-SGTR and evaluate the effectiveness of the strategy when performing Level 2 PSA by considering Multi-barrier Accident Copying Strategy(MACST).

Acknowledgments

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REFERENCES

[1] K. Ross, N. Bixler, S. Weber, C. Sallaberry, and J. Jones, Stata-of-the-Art Reactor Consequence Analyses Project. Uncertainty Analysis of the Unmitigated Short-Term Station Blackout of the Surry Power Station (Draft Report), 2022
[2] Korea Hydro and Nuclear Power Corporation, Probabilistic Safety Assessment for Hanul Units 5&6, 2006
[3] M. Jae. et al, A Study on Multi-unit PSA Regulation Verification Assessment (KINS/AR-1229), Vol.3, 2022
[4] G. Jung, Development of A Risk-Informed Methodology for Assessing Accident Management Strategies in Nuclear Power Plants, 2016