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A Methodology for Evaluating Severe Accident Management Strategies

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1. Introduction

Accident management involves all kind of operator action which can prevent core damage during accident, maintain integrity of containment to terminate the progress of core damage and minimize the off-site radiation releases. Through these actions, they can be contributed to preventing or mitigating the accidents propagation. Severe accidents are defined as those which entail at least an initial core damage, in many cases specified as the overcoming of the regulatory fuel. [1]

After Fukushima accident, the effectiveness of the severe accident management strategy has been attracted worldwide. There is a typical example of severe accident management strategy like Severe Accident Management & Guideline (SAMG). Unfortunately, suitable method for evaluating the accident management strategy is absence until now.

In this study, the evaluation methodology which utilizes the decision tree is developed to evaluate the severe accident management strategies. In addition, we applied the developed methodology to ShinKori nuclear power plant Unit 3, 4 and modeled decision tree for evaluation.

2. Methods and Results

2.1 Decision Tree methodology

The decision tree is a decision support tool that uses a tree-like graph and it can show all of their possible consequences. Decision trees are commonly used in operation research, specifically in decision analysis to help decide a strategy most likely to reach a safety goal.

It is in the form of adding a decision node in the event tree which is widely used in Probabilistic Safety Assessment (PSA). We can easily understand the accident scenarios and its mitigation system by using decision tree. It also shows us that which decision can produce better result with quantified values. The decision tree can involve feasibility, effectiveness and adverse effect generated by decision making.

The shape and description of nodes which used in decision tree are described in Table 1.

Table I: The properties of each node in decision tree

node	shape	description
decision	□	representing decision point
chance	○	representing uncertain quantities
deterministic	◎	representing functions of the values of predecessor nodes
value	◇	representing values

Quantification can be performed by a probabilistic estimation of the reliability data and experts opinion which is similar way to Event tree after developing decision tree model using mentioned nodes.

Figure 1 is a simple example using decision tree to evaluate the severe accident management strategies.

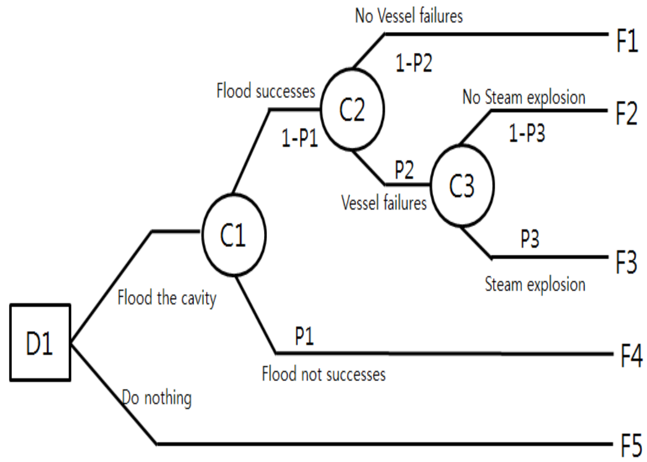

Fig. 1. The example of simple decision tree

To evaluate a severe accident management strategy, below criteria should be considered

- The feasibility of the strategy
- The effectiveness of the strategy
- The possibility of adverse effects
- Information needs
- Compatibility with existing procedure

As mentioned earlier, three criteria which are feasibility, effectiveness and adverse effect need to be considered. The feasibility is a capability of whether the operators can fill the cavity by the required time. This feasibility is described in Fig.1 as C1 node. And the effectiveness is sufficient heat removal to confine molten core in the vessel. It also can be found in Fig.1 as C2. Finally, adverse effect in cavity flooding strategy which is denoted by C3 in Fig. 1 is hydrogen explosion.

Quantification process is required in order to evaluate the above simple decision tree. Table Ⅱ shows the essential value of the cavity flooding strategy for quantification. [2], [3]

Table Ⅱ: Decision Tree value for quantification

Notation	Value	Description
F_1	0	If there is no vessel failure, the conditional probability of early containment failure, $P_{ecf}=0$
F_2	0	If the vessel fails and the melt is quenched, $P_{ecf}=0$
F_3	0.01	If the vessel fails and there is an ex-vessel steam explosion, but no direct containment heating, P_{ecf} is reduced
F_4	0.025	If flooding is not successful; same as " Do nothing"
F_5	0.025	Given in NUREG-1150 ; " Do nothing"
P_1	0.41	The probability that the option is not feasible; that the arrival of water is not timely.
P_2	0.098	The probability that the option is not effective, given the water is there in time.
P_3	0.5	The probability of an adverse effect; i.e. of an ex-vessel steam explosion given water in the cavity.

Quantification results are shown Eq.1 and Eq.2 by using Table Ⅱ.

EV(Do nothing)=0.025 (Eq.1)
EV(Flood cavity)=0.011 (Eq.2)

Through a simple calculation, we can figure out which severe accident management strategy can derive better results. In this case, cavity flooding strategy is better choice than do nothing.

2.2 Development of Decision tree for ShinKori Unit 3, 4.

Many severe accident response equipment are installed in Shinkori unit 3,4 which is APR1400 compared with Optimized Power Reactor(OPR). These new equipment are listed in Table Ⅲ.

Table Ⅲ: Severe accident response equipment in Shinkori Unit 3,4 NPP

1	Design of the reactor building that can withstand severe accident load
2	Installation of cavity flooding system for cooling the molten core
3	Installation of Passive Auto-catalytic Hydrogen Recombiner (PAR) and Ignitor
4	Installation of safety depressurization and exhaust system to prevent high pressure melt ejection and direct containment heating
5	Spiral structure of cavity to capture molten core
6	Emergency containment spray system to control containment pressure

In this study, we modeled the decision tree for cavity flooding strategy evaluation of the severe accident management strategy for Shinkori unit 3,4. To develop decision tree model, containment event tree and decomposition event tree were combined. In addition, some new headings were involved in decision tree from necessity. Fig. 2 is a the result of decision tree which is for cavity flooding strategy evaluation of Shinkori unit 3,4.[4],[5]

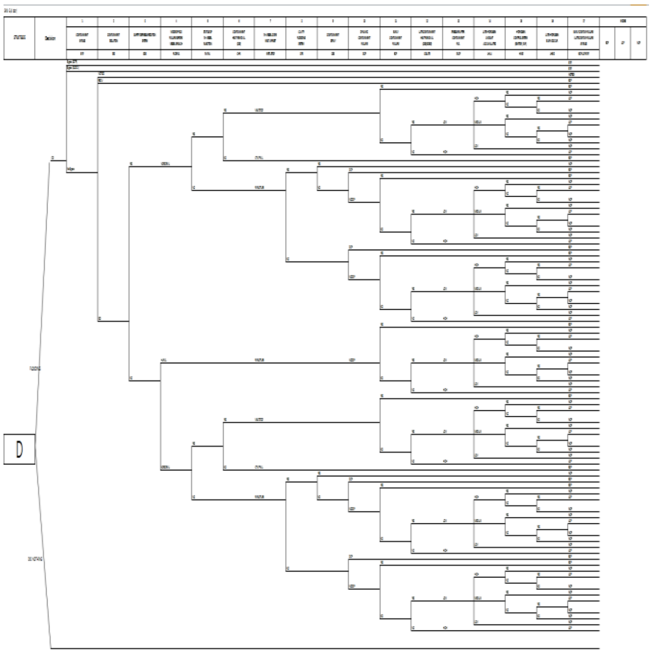

Fig. 2. The result of decision tree modeling

The final results were classified by BYPASS, NOTISO, ECF, LCF and NCF according to references. The decision tree starts from Plant Damage State (PDS). The basic boundary of modeling is from Plant Damage State (PDS) to MELTSTOP, from MELTSTOP to Early Containment Failure (ECF) and from Early Containment Failure (ECF) to final results.

Below Table Ⅳ shows brief description of each heading.

Table Ⅳ: The description of each heading in developed decision tree

	NAME	Description	BRANCH
1	BYP	Containment bypass	bypass(SGTR)/ bypass(ISLOCA)/ No bypass
2	ISO	Containment isolation	NOTISO/RBCM/ISO
3	SDS	Safety depressurization system	YES/NO
4	RCSFAIL	Mode of RCS failure before vessel breach	NORCSFAIL/HLFAIL
5	INVINJ	Status of in-vessel injection	YES/NO
6	CHR	Containment heat removal (CSS)	YES/NO
7	MELTSTOP	In-vessel core melt arrest	MELTSTOP/CTMTFAIL/ RVRUPTURE
8	CFS	Cavity flooding system	YES/NO
9	CSS	Containment spray system	YES/NO
10	DCF	Dynamic containment failure	DCF/NODCF
11	ECF	Early containment failure	YES/NO
12	CSLATE	Late containment heat removal (CSS, ECSBS)	YES/NO
13	PACF	Pressure after containment fail	LOW/HIGH
14	LHAA	Late hydrogen amount accumulated	LOW/MEDIUM/HIGH
15	HMSI	Hydrogen control system (Igniter, PAR)	YES/NO
16	LHBO	Late hydrogen burn occur	YES/NO
17	ECF/LCF/BYP/ NOTISO	Early containment failure/ Late containment failure/ Bypass/Not isolation	ECF/LCF/BYP/ NOTISO

An important heading of cavity flooding strategy is 8th heading which is CFS and 9th which is CSS. Since running CFS is main action of severe accident management strategy, decision tree was modeled around it. If operators do not perform any action which means ‘Do nothing’ strategy, the CFS heading is excluded. As mentioned in method part, the final evaluation of severe accident management strategy is completed if quantification step is finished using developed decision tree. Expert opinion and judgment should be conducted for non-exist data. Then, the evaluation of cavity flooding strategy will be completed.

3. Conclusions

In this study, we developed a methodology to evaluate the severe accident management strategy by using decision tree. In addition, the evaluation was carried out by selecting the cavity flooding strategy. Shinkori unit 3, 4 which is APR1400 is selected and analyzed for reference plant. In order to evaluation, decision tree for cavity flooding is modeled. With reliability data, quantification will be conducted. The utility of other severe accident management strategies can be evaluated with proposed methodology in this study. Finally, it is expected that this methodology improves the safety of nuclear power plant.

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