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A Study on the Influence Diagrams for the Application to Containment Performance Analysis

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격납용기 성능해석을 위한 영향도에 관한 연구

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Abstract

Influence diagram method is applied to containment performance analysis of Young-Gwang 3&4 in an effort to overcome some drawbacks of current containment performance analysis method. Event tree methodology has been adopted as a containment performance analysis method. There are, however, some drawbacks on event tree methodology. This study is to overcome three major drawbacks of the current containment performance analysis method : 1) Event tree cannot express dependency between events explicitly. 2) Accident Progression Event Tree (APET) cannot represent entire containment system. 3) It is difficult to consider decision making problem. To resolve these problems, influence diagrams, is proposed. In the present work, the applicability of the influence diagrams has been demonstrated for YGN 3&4 containment performance analysis and accident management strategy assessments of this study are in good agreement with those of YGN 3&4 IPE. Sensitivity analysis has been performed to identify relative important variables for each early containment failure, late containment and basemat melt-through. In addition, influence diagrams are used to assess two accident management strategies : 1) RCS depressurization, 2) cavity flooding. It is shown that influence diagrams can be applied to the containment performance analysis.

요 약

영향도를 이용하여 영광 3, 4호기의 격납용기 성능해석을 수행하였다. 기존의 사상수목기법을 응용한 격납용기 성능해석은 사건들 사이의 의존 관계를 명확히 나타내기 어렵고, 사고진행사상수목(APET)에서 알 수 있듯이, 격납용기와 같은 복잡한 계통에 적용할 경우 그 의존 관계를 그림으로조차 나타낼 수가 없으며, 또한, 의사결정문제를 다루는 데에도 많은 한계점을 지니고 있다. 이러한 문제점들을 해결하기 위하여 새로이 개발된 방법론인 영향도를 영광 3, 4호기 격납용기 성능해석과 사고관리방안을 평가하는 데에 적용하여 보았다. 본 연구에서 얻은 계산 결과와 기존의 사상수목 기법을 이용하여 계산한 결과와 비교한 결과, 거의 일치하는 계산 결과를 얻을 수 있으면서도 전체 격납용기 계통을 한 눈에 알기 쉽게 그림으로 나타낼 수 있었다. 또한, 영향도가 의사결정문제를 일반적으로 다룰 수 있음을 보이기 위하여 본 방법론을 사고관리방안을 평가하는 데에 이용하여, 원자로 냉각계통 감압과 원자로공동 범람 방안, 두 가지 사고관리방안을 평가하여 보았다. 모두 초기 격납용기 파손에는 나쁜 영향을 주는 것으로 나타났으나, 후기 격납용기 파손이나 증기발생기 세관파손에는 원자로 공동범람과 일차계통 감압이 각각 어느 정도 긍정적인 영향을 미치는 것으로 나타났다. 본 연구를 통하여, 영향도를 이용한 격납용기 성능해석은 사상수목기법을 이용한 분석에 비해, 진행되는 사건들 사이의 의존관계를 보다 명확히 나타낼 수 있고, 또한 영향도는 운전자의 의사결정을 잘 나타낼 수 있으므로 사고관리기법을 평가하는 데에도 쉽게 적용할 수 있음을 알 수 있다. 결론적으로, 본 연구에서는 영향도가 사상수목기법이 지니고 있는 여러 한계점들을 쉽게 극복하며 격납용기 성능해석에 적용할 수 있음을 보였다.

1. Introduction

Containment performance analysis is a very important part of the safety analysis of nuclear power plant because it is directly concerned to public hazard. A concept of event tree[1] has been used for containment performance analysis because it is useful to represent various scenarios of the severe accident. Reactor safety study(WASH-1400)[1] was the first major effort and the first broad-scale application of event tree methodology to assess the risk of nuclear power plants. Event tree method has been modified to apply to nuclear power plants in many aspects. However, several shortcomings have been recognized in the event tree method for application to the nuclear power plant. One of the major problems is that it is difficult to represent dependencies between events and another problem is that the operator intervention cannot be treated generally.

The influence diagrams[2, 3] have been constructed to represent logical relationships between variables associated with the occurrences of key events since it can provide the information contained in an event tree in a more compact manner. This paper describes the use of influence diagrams in nuclear power plants, especially in containment performance analyses and in the assessment of accident management strategies. A demonstration has been made by making a direct application to YGN 3&4 containment performance analysis.

2. Modeling of Influence Diagrams for YGN 3&4

Influence diagrams are graphical language for representing uncertain variable relations. As already explained in the above, event trees cannot represent the dependence relations between variables explicitly. In order to compensate this shortcomings, influence diagrams have been used. More details about influence diagrams are given in Ref.[2]. Influence diagrams are applied to the containment performance analysis of the YGN 3&4 nuclear power plant. In order to construct influence diagrams for YGN 3&4, 9 sub-influence diagrams, which are equivalent to 9 decomposed event trees of the YGN 3&4 IPE[4], have been constructed first. After nine sub-influence

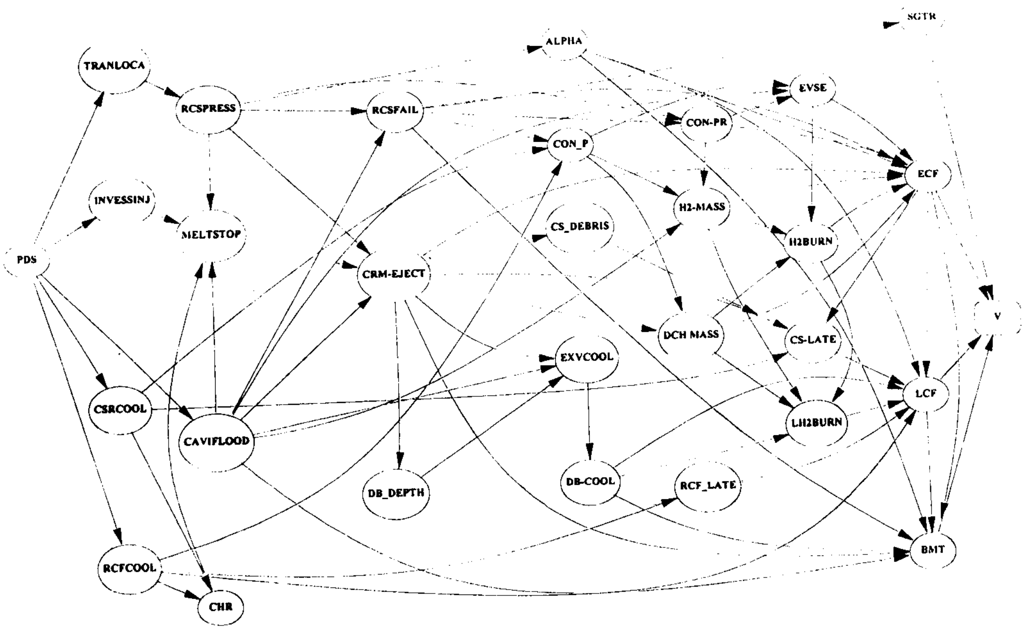

Fig. 1. Influence Diagrams for YGN3&4 Nuclear Power Plant Containment Performance Analysis

diagrams have been constructed, they are combined to construct a full influence diagram for YGN 3&4. Then, value node is added in order to obtain quantitative results. Also, PDSs (Plant Damage States) are added to construct more complete influence diagrams. The early or late containment failure probabilities, basemat melt-through probabilities, and steam generator tube rupture probabilities are changed according to each PDS states. More detailed description about the nodes of influence diagrams are given in Ref.[4]. The final influence diagrams constructed for YGN 3&4 are shown in Fig. 1.

3. Application to YGN 3&4 Containment Performance Analysis

3.1. Evaluation of Influence Diagrams

The influence diagrams for YGN 3&4 that have been constructed as described above have been evaluated. The calculation processes are described in Ref.[2, 3, 5]. As seen in Fig. 1, the influence diagrams for containment performance analysis are too complex to evaluate them analytically. Existing computer code for evaluating influence diagrams has a limitation to treat the number of influencing events and cannot be applied to the influence diagrams for containment performance analysis (Influence diagrams for containment performance analysis have more than eleven influencing events).

In this study, a computer program written in C has been developed for evaluating the influence diagram. The dependent events are treated as dimensions and the states are handled as arrays in this computer program. For example, alpha mode failure probabilities depend on the reactor coolant system failure mode (which has three states: (1) no failure, (2) hot-leg break, and (3) steam generator tube rupture) and the reactor coolant system pressure (which has 3 states (1) high, (2) medium, and (3) low). In this alpha mode failure event, there are two states, i.e., alpha mode failure and no failure. Therefore, alpha mode failure probabilities are expressed as ALPHA [3][3][2] in the present program.

Using chain rules, three equations[6] for early containment failure probability, late containment failure probability, and basemat melt-through probability can be formulated using algorithms for calculation developed in Ref [6].

In this study, input data is based on that of YGN

Table 1. Results of the Influence Diagrams Evaluation

	PDS	Probability of Containment Failure				
	Frequency	No CF (%)	ECF (%)	LCF (%)	BMT (%)	Bypass (%)
PDS 3	1.4	97.8	<0.1	<<0.1	0.2	2.0
PDS 4	0.0025	97.5	<0.1	0.2	0.2	2.0
PDS 6	0.0008	97.9	<0.1	0.0	0.0	2.0
PDS 7	0.0004	94.0	<0.1	2.2	1.8	2.0
PDS 11	0.46	94.4	0.3	2.9	1.4	1.0
PDS 12	0.0004	73.4	0.3	<0.1	25.3	1.0
PDS 13	0.0005	71.3	0.3	2.2	25.3	1.0
PDS 16	13.66	50.4	0.8	30.2	17.6	1.0
PDS 17	28.77	97.7	0.3	0.0	<0.1	2.0
PDS 18	0.16	93.8	0.3	2.2	1.7	1.0
PDS 19	0.0024	71.8	0.2	1.7	25.3	2.0
PDS 20	0.0004	39.7	30.3	26.8	1.2	1.0
PDS 21	0.07	45.6	5.7	30.1	17.6	2.0
PDS 22	0.15	95.8	0.5	<0.1	1.7	2.0
PDS 23	0.05	93.6	0.5	2.2	1.7	2.0
PDS 24	0.17	71.7	0.3	1.7	25.3	1.0
PDS 25	0.02	59.6	10.4	26.8	1.2	2.0
PDS 26	2.96	50.5	0.8	30.1	17.6	1.0
PDS 27	9.84	99.9	<0.1	<<0.1	<<0.1	0.0
PDS 28	0.02	99.7	<0.1	0.2	0.1	0.0
PDS 30	3.55	97.1	0.7	<0.1	2.2	0.0
PDS 31	1.42	95.0	0.8	3.0	1.2	0.0
PDS 32	0.004	56.9	0.8	3.0	39.3	0.0
PDS 33	0.0005	58.1	10.7	30.3	0.9	0.0
PDS 34	0.01	41.7	0.8	30.2	27.3	0.0
PDS 35	6.17	99.9	<0.1	<0.1	<0.1	0.0
PDS 36	0.04	99.7	<0.1	0.2	0.1	0.0
PDS 37	0.32	3.4	95.0	1.5	<0.1	0.0
PDS 38	0.08	99.9	0.1	<0.1	<0.1	0.0
PDS 39	1.71	95.9	0.1	2.2	1.8	0.0
PDS 40	0.05	65.8	0.1	2.2	31.9	0.0
PDS 41	0.21	61.0	10.3	27.4	1.3	0.0
PDS 42	2.61	46.9	0.3	30.6	22.2	0.0
PDS 43	0.05	99.9	<0.1	<0.1	<0.1	0.0
PDS 44	0.0005	99.8	<0.1	0.1	0.1	0.0
PDS 46	5.47	95.2	0.2	<0.1	1.7	0.0
PDS 47	10.79	65.7	0.2	2.8	1.8	0.0
PDS 48	0.05	65.7	0.1	2.2	32.0	0.0
PDS 49	0.004	61.0	10.3	27.4	1.3	0.0
PDS 50	0.06	46.9	0.3	30.6	22.2	0.0

3&4 IPE, and all plant damage states are treated to show the flexibility of influence diagrams. It is assumed that there is only one accident consequence for a given event (for example, early containment failure and late containment failure can not occur at the same time). These calculation results are shown in Table 1.

3.2. Sensitivity Analysis

In order to identify variables which are more effective to the consequences, sensitivity analysis are performed. There are many kinds of sensitivity analysis methods[7]. However, in this study, one at a time sensitivity analysis method is chosen. Only a probability value of one variable is changed at each calculation and every other variables remain fixed. Calculations have been performed three times for each of variables to identify its linearity. As you can see on Fig.2 through 4, the changing rate of each variable is linear because the interaction between variables is not considered in this study. Major variables to each of early containment failure, late containment failure and basemat melt-through are listed in Table 2 through 4 respectively.

4. Application to Accident Management

Influence diagrams have been proposed as an alternative method for the assessment of accident management strategies[3]. In this study, influence diagrams have been applied to the assessment of accident management strategies for the YGN 3&4 plant. There are a number of accident management strategies to prevent or mitigate severe accident risks. Reactor coolant system depressurization and cavity flooding are identified as those of main issues among many accident management strategies. These two accident management strategies are assessed in this study. Reactor coolant system depressurization strategy is a strategy to depressurize the primary system during accident conditions. Cavity flooding strategy is

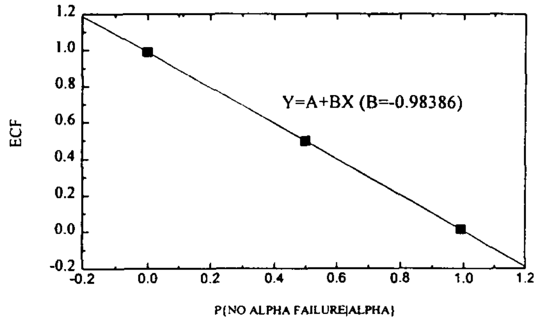

Fig. 2. ECF Sensitivity Analysis to Alpha Mode Failure Probability

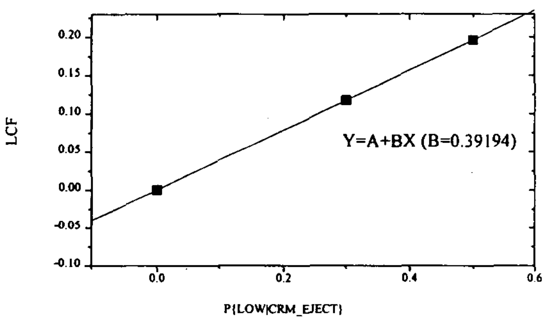

Fig. 3. LCF Sensitivity Analysis to Amount of Ejected Corium

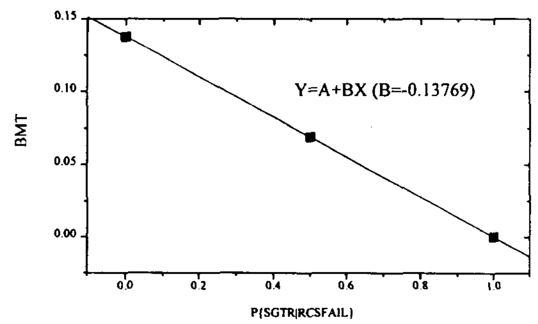

Fig. 4. BMT Sensitivity Analysis to RCS Failure Probability

a strategy to fill the reactor cavity with coolant from safety system during accident conditions. There are advantages and disadvantages for both cases. In the case of depressurizing the reactor coolant system, steam generator tube rupture and vessel breach can be prevented but the likelihood of alpha mode fail-

Table 2. Sensitivity to Early Containment Failure

Parameters	Value B (Y=A+BX)	Importance
ALPHA	−0.98386	1
EVSE	−0.43851	2
CRM−EJECT	0.02040	3
H2−MASS	0.00854	4
MELTSTOP	0.00685	5
CON−PR	0.00614	6
DCH−MASS	0.00614	6
H2−BURN	0.00614	6
CON−P	0.0048	9
RCSFAIL	−0.00375	10

Table 3. Sensitivity to Late Containment Failure

Parameters	Value B (Y=A+BX)	Importance
CRM−EJECT	0.39194	1
ALPHA	0.3032	2
CS−LATE	0.30208	3
EVSEA	−0.3016	4
MELTSTOP	0.3016	4
RCSFAIL	−0.19795	6
RCF−LATE	0.1663	7
H2−BURN	0.13568	8
LH2BURN	0.0643	9
EXVCOOL	−0.00038	10
H2−MASS	−0.00015	11

Table 4. Sensitivity to Basemat Melt-Through

Parameters	Value B (Y=A+BX)	Importance
RCSFAIL	−0.13769	1
CS−LATE	0.13769	1
ALPHA	−0.13733	3
MELTSTOP	0.13713	4
CRM−EJECT	0.13711	5
EVSE	−0.13031	6
LH2BURN	−0.06432	7
EXVCOOL	0.02754	8

ure increases. In the case of cavity flooding, vessel breach can be prevented but the likelihood of ex-vessel steam explosion becomes much higher. Therefore, the assessment of these strategies is performed to assess their effect on the containment integrity that may cause fatal risks. For this work, decision nodes are added to the reactor coolant system pressure chance node and the cavity flood chance node, as shown in Fig. 2. When operator decides to depres surize reactor coolant system, the pressure of reactor coolant system becomes low. If operator decides to flood coolant into the reactor cavity, cavity is flooded

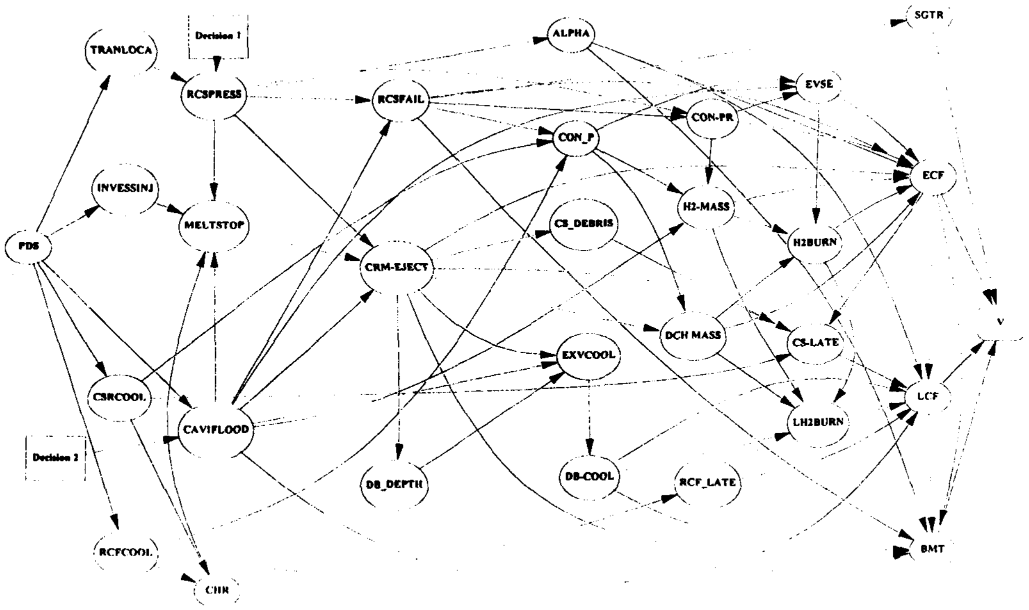

Fig. 5. Influence Diagrams for Accident Management

Table 5. Results of Assessing Accident Management Strategies

Decision	No CF (%)	ECF (%)	LCF (%)	BMT (%)	SGTR (%)
Do nothing	50.60	0.76	30.12	17.56	1.00
Depressurize	41.30	0.80	30.40	27.52	0.00
Flood	59.57	10.41	26.78	1.24	2.00
Good Alternatives	Flood	Do nothing	Flood	Flood	Depressurize

in all sequences. Influence diagrams for the accident management are shown in Fig. 5. Where, the decision node of 'Decision1' represents operator's action to depressurize RCS pressure and the decision node of 'Decision2' represents operator's action to flood the cavity. Table 5 shows results of present calculations. Early containment failure probabilities are increased in both cases because depressurization of RCS makes alpha mode failure probability increase and the flooding of cavity may cause ex-vessel steam explosion[8]. But late containment failure and basemat melt-through probabilities tend to decrease when flooding strategy is employed. The depressurization strategy has a favorable effect on the steam generator tube rupture.

5. Conclusions and Recommendations

Influence diagrams have been applied to the containment performance analysis and to assess accident management strategies. The influence diagram has been applied to 48 different kinds of accident sequences. As a tool for evaluations, a computer program to evaluate YGN 3&4 influence diagrams has been developed and used in this study.

Influence diagrams are also applied to the assessment of accident management strategies, i.e., RCS depressurization and cavity flooding. It is shown that influence diagrams are very flexible to apply for assessing accident management strategies. Results of calculation show that cavity flooding has a favorable effect on the late containment failure and basemat melt-through. RCS depressurization has a favorable effect on the steam generator tube rupture. But early containment failure probability becomes higher in both cases due to the alpha mode failure and the steam explosion, respectively. From the present study, the following conclusions can be made :

(1) It is possible to identify dependencies between uncertain variables explicitly by using influence diagrams in containment performance analysis.
(2) It is easier to use influence diagrams in the case of a complex systems such as the containment performance analysis.
(3) Influence diagram method is useful for decision making problem such as assessing severe accident management strategies.

Acronyms

PDS	Plant damage states
RCSPRESS	Reactor coolant system pressure during core damage
INVESSINJ	Status of in-vessel injection
CSRCOOL	Containment recirculation cooling
RCFCOOL	Containment fan cooling
CAVLED	Cavity flood or not
CHR	Containment heat removal system
RCSFAIL	Mode of induced primary system failure
DB-DEPTH	Depth of debris pool
MELTSTOP	Debris cooled in vessel
CRM-EJECT	Amount of corium ejected out of cavity
CON-P	Containment pressure at reactor vessel failure
CON-PR	Containment pressure rise due to RCS blowdown at RV failure
EVSE	Ex-vessel steam explosion
DCH-MASS	Fraction of mass involved in Direct

	containment heating
H2-MASS	Amount of hydrogen produced in vessel
CS-DEBRIS	Excessive debris in sump causes spray failure
DB-COOL	Debris cooled in cavity
EVSE	Ex-vessel steam explosion
H2BURN	Hydrogen burn occur before/at RV rupture without DCH fraction of mass involved in DCH
CS-LATE	No late recirculation spray failure
EXVCOOL	Debris coolability in the reactor cavity
LH2BURN	Hydrogen burn lately
RCF-LATE	Containment fan cooler operate lately
ALPHA	Alpha-mode Containment failure
SGTR	Steam generator tube rupture
ECF	Early containment failure
LCF	Late containment failure
BMT	Basemat melt through
YGN 3&4	YoungGwang unit 3&4
IPE	Individual plant examination
Decision 1	Operator's action to depressurize RCS pressure
Decision 2	Operator's action to flood cavity.

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