

# Development of Simulation and Visualization System for Understanding the Physical Phenomena of Accident Sequences in PSA

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## Abstract

This paper presents a framework in which, accident sequences are obtained by a dynamical event tree/GO-FLOW combination, and a specific accident sequence is expressed visually using a plant simulator and visualization system, along with accident progress. An advanced marine reactor: MRX is taken up, and thermo-hydrodynamic behavior is calculated by the MARCH2 code. With the completion of this system, it is overcome the difficulty in comprehending the analysis results of PSA.

## 1 Introduction

Nuclear power plants are required to establish high reliability and safety. Probabilistic Safety Assessment(PSA) has been introduced into nuclear field and used in many activities such as plant design, safety assessment, risk based regulation, accident management and so on. But, for non-PSA specialist, it is usually difficult to understand the results of PSA, especially to comprehend what phenomena is represented by a specific accident sequence. Non-specialists have to believe analysis conditions and hypotheses, and therefore they can not judge the adequacy of PSA results.

The purpose of this paper is to present a framework in which, accident sequences are obtained by a dynamical event tree/GO-FLOW[1] combination, and a specific accident sequence is expressed visually using the plant simulator and visualization system, along with accident progress.

The following research items are being performed for the development of the system. (1) Research on identification function of major accident sequences. The GO-FLOW methodology and a dynamical event tree are used for the identification of accident sequences. (2) Development of a simulator of plant

accident progression. In the present study, Advanced Marine Reactor: MRX[2] is taken up, and thermo-hydrodynamic behavior is calculated by the MARCH2[3] code. (3) Research on the expression method for plant accident progression.

## 2 Dynamical Event Tree

In a traditional event tree, headings are arranged in order of occurrence, but the time factor is not apparently considered and a static analysis is performed. In the GO-FLOW methodology, time dependent success probabilities of a system operation are obtained. A dynamical event tree[4] has been developed in order to directly utilize the analysis results of GO-FLOW for branching probabilities of headings in an event tree. The dynamical event tree has following functions.

(1) Combination with the GO-FLOW: A signal number in the GO-FLOW analysis can be assigned to a heading in the event tree. In this case, the branching probability changes with time progress. So, occurrence probabilities of accident sequence are calculated for all the time points.

(2) Introduction of the time points: Time point number is given to a heading. Branching at the heading does not occur before the given time point, i.e. an event occurs at a specified time.

(3) Same event can be placed at multiple places in the event tree: Same event but with different time points can be placed at more than two places as heading in the event tree.

(4) Automatic rearrangement of heading order: If the ordering of the headings differs from time points given to headings, automatic rearrangement is performed based on the time points. In this case, the structure of event tree is preserved as far as possible.

(5) Dependency between headings: Dependency can be given for more than two events appeared on headings by defining conditional occurrence probabilities.

## 3 Treatment of the dependency between headings

### 3.1 Between Two Headings

If two events A and B appear as headings in this order, the dependency between A and B is expressed by the conditional occurrence probability of B as  $P(B/A) = \rho$ .

The value of  $\rho$  is from 0.0 to 1.0. If  $\rho$  equals  $P(B)$ , then A and B is independent. If  $\rho$  is less than  $P(B)$ , there is a negative correlation between A and B. The value of  $\rho P(A)$  must be less than  $P(B)$  i.e. less than the total occurrence probability of B, then  $\rho$  is less than  $P(B)/P(A)$ .

If the order of A and B changes and B appears first, then we give the conditional

occurrence probability  $P(A/B)$  instead of  $P(B/A)$ . The value of  $P(A/B)$  equals  $P(B/A)P(A)/P(B) = pa/b$ , where we denote  $P(A)$  and  $P(B)$  by  $a$  and  $b$ , respectively.

### 3.2 Between Three Headings

Consider an event tree which has three headings A, B and C as shown in the figure 1. The occurrence probability of each sequence can be expressed by conditional probabilities as written in the figure 1.

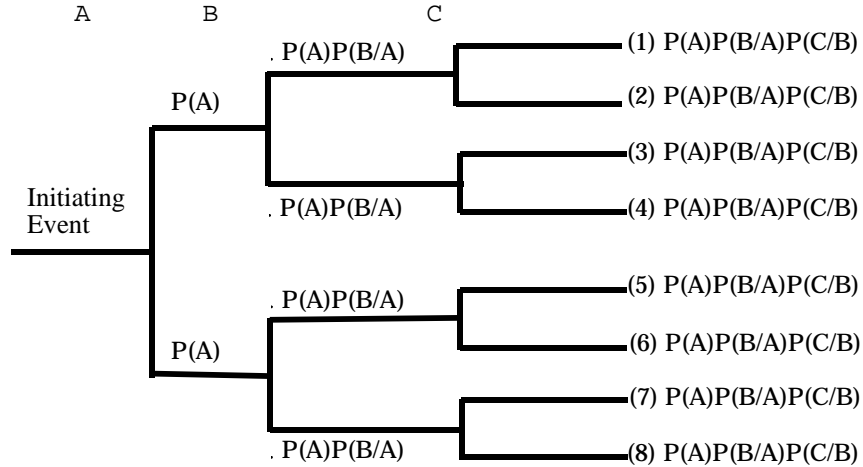


Figure 1. Event tree with three headings A, B and C.

The dependencies between A, B and C can be defined by the conditional occurrence probabilities as  $P(B/A)=\rho_1$ ,  $P(C/B)=\rho_2$ .

From the relation of  $P(B)=P(A)P(B/A) + P(\bar{A})P(B/\bar{A})$ , we could deduce the following equation.

$$P(B/\bar{A})=1.0/P(\bar{A}).\{P(B)- P(A)P(B/A)\} = 1.0/(1-a).(b - a \rho_1).$$

In the same way, the following relations can be obtained.

$$P(\bar{B}/A) = 1.0- \rho_1$$

$$P(\bar{B}/\bar{A}) = 1.0/(1-a).(1 - a - b + a \rho_1)$$

$$P(C/\bar{B}) = 1.0/(1-b).(c - b \rho_2)$$

$$P(\bar{C}/B) = 1.0 - \rho_2$$

$$P(\bar{C}/\bar{B}) = 1.0/(1-b).(1 - b - c + b \rho_2)$$

From the above expressions, we could express the occurrence probabilities of sequences (1) - (8), by  $a$ ,  $b$ ,  $c$ ,  $\rho_1$ ,  $\rho_2$ . For example, the sequence (6) is

$$a(1- \rho_1).1.0/(1-b).(c - b \rho_2).$$

### 3.3 General Expression

If an event  $X$  has dependencies with events  $A_1, A_2, \dots, A_n$ , the occurrence probability  $P(X, A_1, A_2, \dots, A_n)$  becomes as follows,

$$\begin{aligned} P(X, A_1, A_2, \dots, A_n) &= P(X)P(A_1, A_2, \dots, A_n/X) = P(X)P(A_1/X)P(A_2/X) \dots P(A_n/X) \\ &= P(X).P(A_1) P(X/A_1)/P(X).P(A_2) P(X/A_2)/P(X) \dots P(A_n) P(X/A_n)/P(X) \\ &= a_1 a_2 \dots a_n \cdot \rho_1 \rho_2 \dots \rho_n / x^{n-1}, \end{aligned}$$

where  $a_1, \rho_1, x$  are  $P(A_1), P(X/A_1), P(X)$ , respectively.

In the same way,

$$P(\bar{X}, A_1, A_2, \dots, A_n) = a_1 a_2 \dots a_n (1-\rho_1)(1-\rho_2) \dots (1-\rho_n) / (1-x)^{n-1}.$$

For a sequence in which the event  $A_k$  does not occur, we use the expression:

$$P(X/\bar{A}_k) = 1 / (1 - a_k \rho_k).$$

## 4 Simulation of Accident phenomena

The combination of GO-FLOW and Dynamical event tree identifies accident sequences. For a selected accident sequence, a simulation analysis is performed by the MARCH 2 code. A management system is developing by using the expert system G2, which receives event tree information, selects a specific accident sequence, prepares input data for MARCH 2 code, starts the MARCH 2 code, and visualizes the plant condition based on the analysis results.

In the present study, an Advance Marine Reactor MRX, which is designed by the Japan Atomic Energy Research Institute for the future type marine reactor, is taken up as an object plant.

Input data for the MARCH 2 code are classified into four categories as follows. (a) Analysis and Boundary conditions, (b) Options for analysis models, (c) Fundamental structural data of MRX reactor, (d) Others. The category (a) is further divided into five items (a-1)General information for an analysis as a title, (a-2)Initial condition of the MRX plant, (a-3)Timing and kinds of events, (a-4)Status of sub-systems of MRX plant, (a-5)Other condition necessary for a simulation analysis.

The data of category (a) have to be made for each accident sequence, but other data can be commonly used for the simulation analysis of MRX plant. Input data for the MARCH2 code are almost automatically produced from the information of headings in event tree. An analyst determines undesignated input data by an interactive system.

## 5 Visualization of Accident phenomena

The thermo-hydrodynamic behavior is calculated by the simulation analysis code MARCH 2, but the results are usually expressed by numerical values as outputs of a line printer. The present framework shows us the simulation results visually with the support of graphical user interface of the expert system G2.

Plant states are expressed as shown in Figure 2, which is the main part of the MRX plant system.

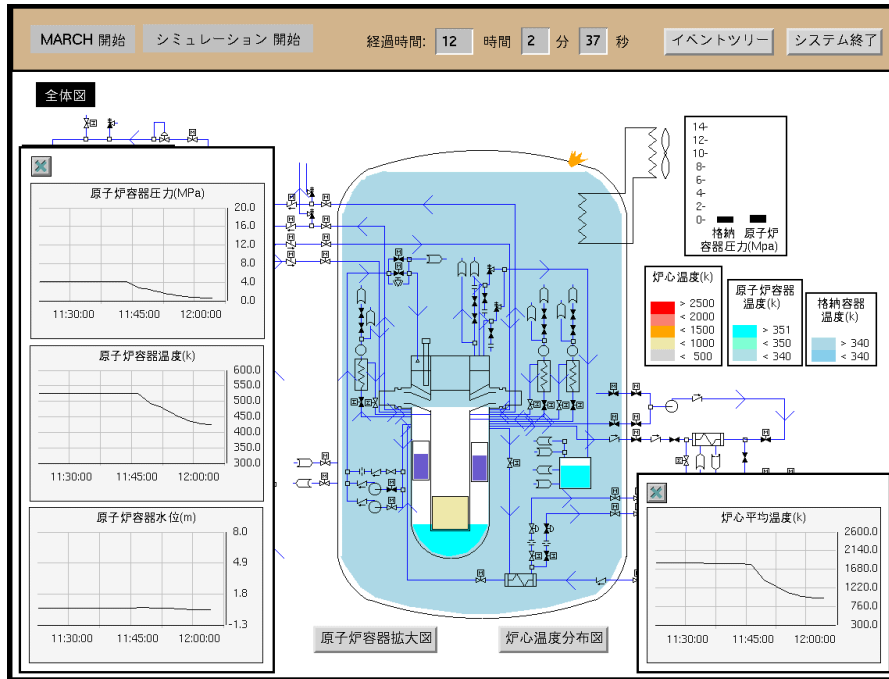


Figure 2. An example of the visualization of the simulation result.

Simulation results are presented in the form of animation after the analysis has been completed. In figure 2, the water levels in the containment and pressure vessels are shown and the temperature levels are indicated by the color. The color scales are shown in the boxes on the right middle of the figure. Main components have pop-up graphs, which show changes of main process values such as temperature, pressure, flow rates, water level.

At the present time, there are two other kinds of animations, more detailed figure of the pressure vessel and temperature profile of the reactor core. The

demonstration of this system is planned during the conference.

## **6 Conclusions**

Simulation and visualization system for understanding the physical phenomena of PSA results is now developing as the application of GO-FLOW methodology.

A dynamical event tree has been developed in order to directly utilize the analysis results of GO-FLOW for branching probabilities of headings in an event tree. Input data for the MARCH 2 simulation code is almost automatically obtained from the information of an accident sequence identified by the GO-FLOW /Dynamical event tree combination.

Simulation results are visually expressed with the support of graphical user interface of the expert system G2, after the simulation analysis has been completed.

With the completion of this system, it is overcome the difficulty in comprehending the analysis results of PSA. Not only the PSA specialist but also general users can easily understand the meanings of PSA results, and it becomes easy to verify analysis conditions, analysis hypotheses, and adequacy of analysis results.

This analysis framework can also be applied to chemical plants, transportation and communication systems. This research is supported by the special fund of Science and Technology Agency, Japanese Government (From 1994 to 1998 fiscal year).

## **References**

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