QUANTITATIVE ACCIDENT ANALYSIS IN NUCLEAR POWER PLANTS

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ABSTRACT

The present study addresses some ideas concerning accident analysis in nuclear power reactors. A simple algorithm was adopted and expanded to cope with: * Probabilities of all sequences involed in event treees, * Clustering of sequences into groups according to certain significance criteria, and * Time varient unavailability estimation. As a case study, the eevent tree for small LOCA was analyzed and the results, compared with those from other codes, are presented.

INTRODUCTION

Event tree technique is usually applied to descrribe the consequences of different initiating events in safety analysis studies of nuclear power plants. Quantitative evaluation of event tree should be proceeded by fault tree analysis of estimate the unavailability of top events appearing in the event trees. These top events may include the unavailability of one or more engineered safety feature system (ESF), that are mainly designed to prevent or mitigate radiation release to environment.

EVALUATION OF COMPONENT UNAVAILABILITY

The first step to be evaluated in the unavailability of a component that undergoes periodic testing with the following testing; test period (T), test down time (τ, probability of test induced failure (α) and repair time (μ).

The average unavailability of the component, q, can be given by [1]

$$q = P_o\left[1 - \frac{1}{\lambda T}\left\{1-(1-\alpha+\alpha e^{\lambda/\mu})e^{-\lambda(T-\tau)}\right\}\right]$$

$$+ P_1\left[1 - \frac{\tau}{T} - \frac{1}{\lambda T}\left\{e^{-\lambda(T-\tau)} \quad e^{\lambda/\mu}\right\}\right] \qquad (1)$$

where P_o $\equiv$ the probability of the component to be in the failure state,

$$P_o = q_{10}/(1+q_{10}-q_{00}), \qquad (2)$$

P_1 = the probability of the component to be in the success state,

$$P_1 = 1 - P_o \qquad (3)$$

$$q_{00} = e^{-\lambda T}\left[1+\alpha(e^{\lambda(\tau+\mu)}-1)\right] \qquad (4)$$

and

$$q_{10} = e^{-(T-\tau-1/\mu)} \qquad (5)$$

where q_{00} and q_{10} are the transition probabilities.

TOP EVENT EVALUATION

The present investigation adopts the TDPP computer program algorithm [2] to compute the exact probability of the top event. The algorithm is a top-down one working without reference to cut sets of the fault tree under investigation. A simple bottom-up modularization of fault tree is performed before starting the recursion. The algorithm was expanded to evaluate all top events of engineered safety features (ESF) systems included in the event tree under investigation.

TIME EFFECT

The program is also designed to evaluate the top event of a fault tree at different times. The failure rates of the component are introduced into the data input file of the fault tree, ald components are considered to be non-repairable. The unavailability of the compponent is evaluated by:

$$q(t) = 1 - e^{-\lambda t} \qquad (6)$$

ACCIDENT SEQUENCE EVALUATION

Considering certain event tree, the expanded TDPP code is capable to:

. Compute the probabilities of the top events for all systems involved.
. Compute the probability of each sequences of events in the event tree.
. Compute the sum of sequences'probabilities that are pertained to a pressigned group.
. Check that all sequence propabilities are summed to one.

Figure (1) illustrates the flow chart of the program that conducts the above mentioned computational steps.

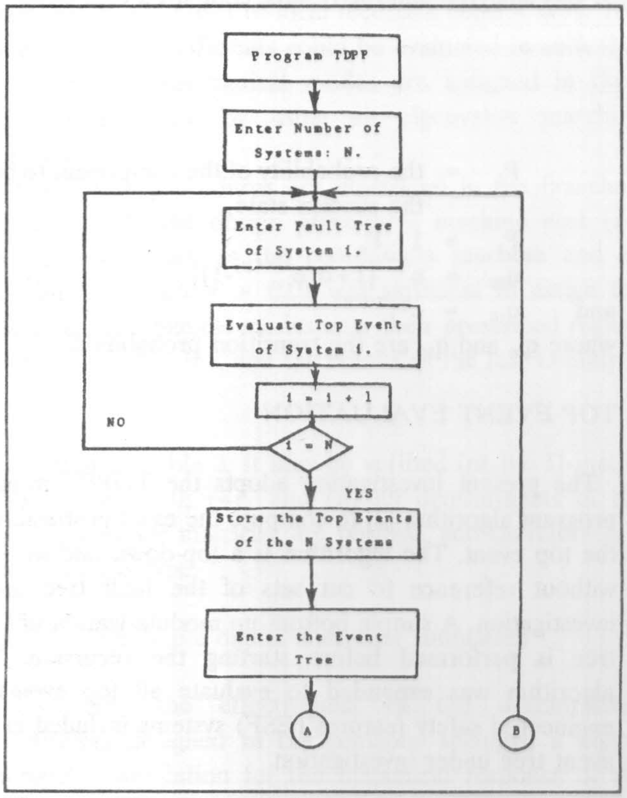

Figure 1. Flow chart of the Program.

CATEGORIES OF ACCIDENTS SEWUENCES

All sequences can be clustred in groups according to certain significance criteria. These groups may be identified by colours signalled to the operator in the control room (or simulator) of a nuclear power plant (NPP), upon the appearance of this display, the operator will excute the corrective action(s) listed clearly in the operational procedure. The main objective of this categorization is to improve the reliability of man-machine interface in NPPs.

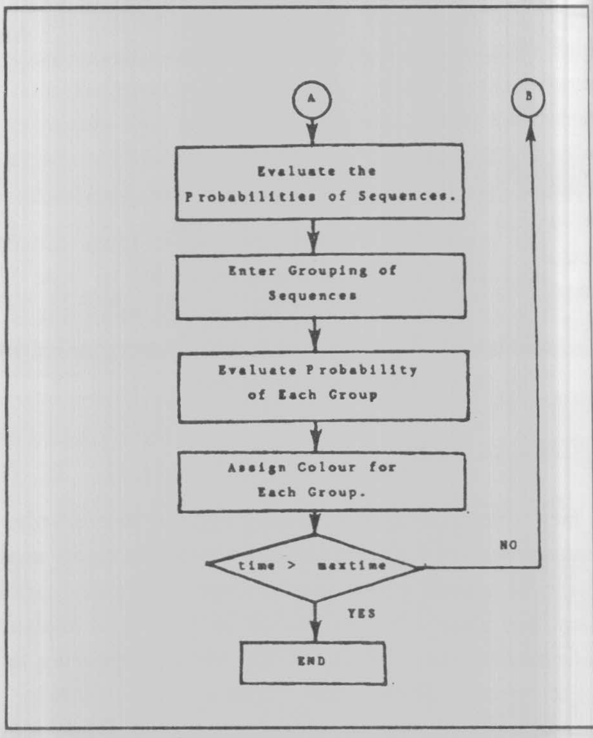

Figure 1. Continue.

CASE STUDY

The accident sequences of small LOCA show in Figure (2), (44 sequences) [3], could be grouped into three groups; on core melts, late core melt and early cere melt. Table (1) illustrates the sequences in each group, as well as the total probability of each group.

In case of repairable component the unavailability of the component will be given by

$$q(t) = \frac{\lambda}{\lambda+\mu}(1-e^{-(\lambda+\mu)t}) \quad (7)$$

where $\lambda$and μ represent the failure rate and repaire rate of the component.

RESULTS

Figure (2) shows the variation of top event unavailability with time for the Sodium Hydroxide Addition (SHA) system in typical NPP [3]. Table (1) shows some results on a sample fault tree as compared which obtained from PREP-KITT Code [4,5].

Table 1. Top event unavailability for nonrepairable sample tree.

Time (HR)	Te by TDPP Mont carlo (10-3)	Exact results	Te by PREP - KITT Code Upper Bound	Envelopes		
	Q(t)	Q(t)	Q(t)	Q(t)min	Q(t) max	Q(t)
0.0	0.0	0.0	0.0	0.0	0.0	0.0
1.0	3.5659E-3	3.49E-3	3.56E-3	3.45E-3	3.57E-3	3.47E-3
2.0	1.3472E-2	1.32E-2	1.37E-2	1.29E-2	1.38E-2	1.30E-2
3.0	2.9745E-2	2.80E-2	2.97E-2	2.70E-2	3.00E-2	2.85E-2
4.0	5.0803E-2	4.70E-2	5.06E-2	4.48E-2	5.15E-2	4.68E-2
5.0	7.6172E-2	6.95E-2	7.58E-2	6.54E-2	7.78E-2	6.90E-1
10.0	2.4441E-1	2.12E-1	2.41E-1	1.86E-1	2.64E-1	2.08E-1

Table 2. Grouping sequence probabilities for PWR small LOCA.

Group number	Sequences in Group	Total Probability of the Group
G1 No Core Melt	S1, S1C , S1CH	0.826
G2 Late Core Melt.	S1H, S1HI, S1G, S1GH, S1GHI, S1CH, S1F, S1FH, S1FI, S1FHI, S1D, S1DI, S1DG, S1DGI, S1DF, S1DFI S1CH, S1CHI, S1CH, S1CHI, S1CG, S1HG, S1CGI, S1CF, S1CHGI, S1CHF, S1CD, S1CDI, S1CDG, S1CDGI, S1 CDF	0.138
G3 Early Core Melt.	S1K, S1KI, S1KG, S1KGI, S1KF, S1KFI, S1KC, S1KCG, S1KCF,S1B,S1BK	0.036

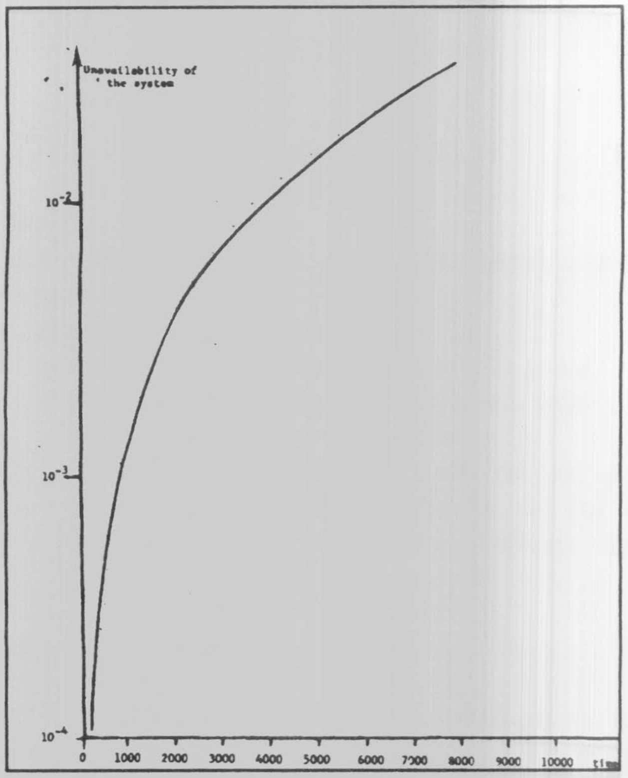

Figure 2. Variation of unavailability of SHA system.

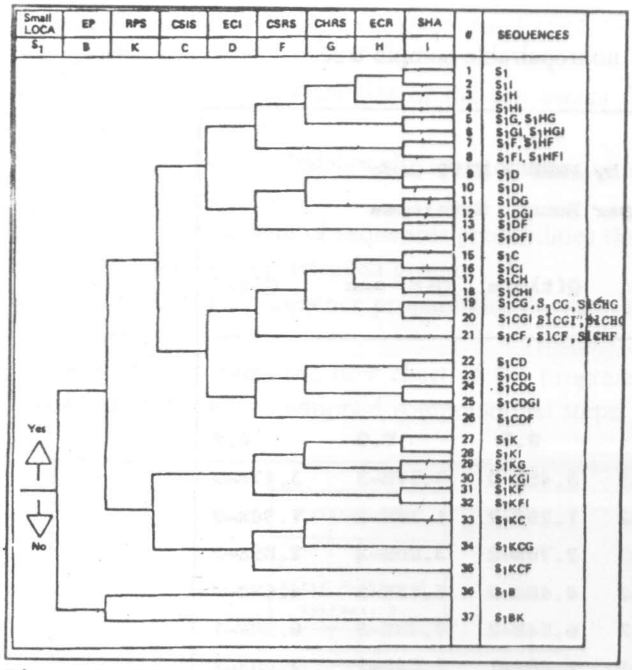

Figure 3. PWR small LOCA (S1, 2-6 inch diameter) in RCS (adapted from Ref. [3]).

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