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Development of Source Term Generation Algorithm without Grouping Process

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1. Introduction

In level 2 probabilistic safety assessment (PSA) methodology, a large number of accident scenarios considering several initiating events and system/component status would be generated. Analyzing the accident scenarios with modern severe accident analysis computer code has been considered as computationally prohibitive. Therefore, in practice, the accident scenarios which are expected to behave similarly in accident progressions are grouped and a representative scenario is selected for further analysis [1]. As shown in Fig. 1, the grouping processes are conducted at two stages of PSA; level 1 PSA sequences (Plant Damage States) and level 2 PSA sequences (Source Terms). However, this grouping process would introduce an uncertainty in PSA results.

As an effort to reduce the uncertainty in PSA methodology and improve the reliability of PSA result and thanks to the increased modern computing power, the novel PSA method without grouping process has been investigated as shown in Fig. 2. Due to eliminating the grouping process, several thousands of accident scenarios should be simulated, which means the same number of input files should be prepared. Without automatization of input file preparation, simulating all accident scenarios would be very time-consuming and cumbersome.

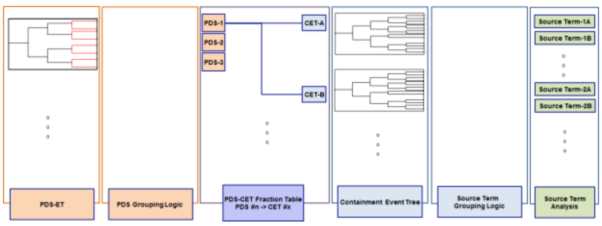

Fig. 1. Conventional Level 2 PSA Process (w/ grouping)

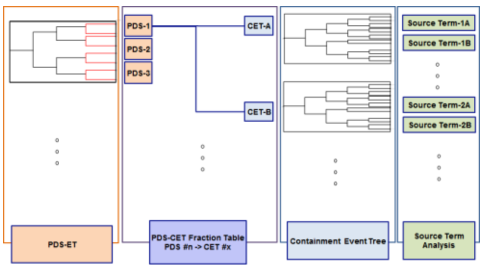

Fig. 2. Proposed Level 2 PSA Process (w/o grouping)

In this study, the algorithms for source term generation have been developed. PSA result files are loaded and the accident sequences are generated by eliminating grouping steps. Then, the input files for accident simulation (e.g., MAAP or MELCOR) with the whole accident sequences are generated. The whole processes are conducted automatically and a user only needs to specify the file names. The algorithm is demonstrated with MAAP severe accident code.

2. Methods

The algorithm consists of two parts: combined sequence generation and MAAP input preparation. In order to generate combined sequences, the PSA results are required. Once the combined sequences are constructed, the MAAP input files can be prepared by adding/modifying lines to control the components corresponding to sequence headings, e.g., pump on/off or valve on/off.

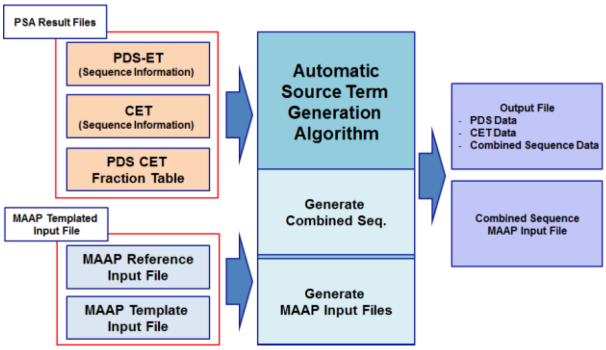

Fig. 3. Schematics of Source Term Generation Algorithm

2.1 Combined Sequence Generation

Combined sequences can be generated by combining core damage sequences in level 1 PSA and containment event sequences in level 2 PSA. If grouping process used, level 1 PSA sequences are grouped before connected to containment events. Then, level 2 PSA sequences are grouped before source term analysis. Thus, a manageable number of sequences for accident simulations would be generated. On the other hand, in this study, the grouping process is eliminated, which means all level 1 PSA sequences are directly connected to containment events and the resulting level 2 PSA sequences are not grouped.

The information on sequences of level 1 PSA and level 2 PSA is loaded by reading corresponding PSA result files. It is important to note that each level 1 PSA sequence is branched to several level 2 PSA sequences with different fractions. The algorithm reads the all necessary data and constructs the combined sequences by coupling the level 1 PSA sequences to the proper level 2 PSA sequences.

2.2 MAAP Input File Generation

MAAP input files are prepared by adding or modifying lines in a reference input file according to the combined sequence headings. Firstly, the reference input file for each initiating event is prepared. In this reference input file, the initiating accident conditions (e.g., component/system malfunctions or pipe breaks) are defined. Secondly, the template files are prepared, in which the lines for defining the operator actions or major accident progression changes are included. Basically, a template file is prepared for each heading of plant damage state event trees and containment event trees. Thirdly, the input files are generated for all combined sequences. For each sequence, a proper reference input file is chosen, and then according to headings, the corresponding template files are added into the reference file. Because there are many different combinations of accident phenomena and component/system availability considered in PSA, there are a lot of exceptions and special rules applied.

3. Numerical Demonstration

The algorithm has been applied to the OPR1000. In Fig. 4~6, the information about level 1/2 PSA sequences and PDS-CET fraction contained in PSA output files are illustrated. The algorithm has been implemented by using Python code [3] and the generated combined sequences are summarized in Fig. 7.

The number of initiating events considered is 23. The total number of combined sequences is 16,964. As can be seen in Table I, the number of sequences is increased by several orders. It is important to note that the number of combined sequences can be varied by changing the frequency limit for consideration, which means that the user can reduce the number of combined sequences by neglecting sequences with very low frequency.

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"Sequence Information"
"SEQ#","FREA","STATE","CONSEQUNCE","F_SEQUNCE","S_REMARKS","R_METRICS"
1,"6.263454e-007","","","","",""
2,"","OK","","IE-LLOCA /SIT /LPI /HPR /HPH /CSR","",""
3,"2.251e-9","37","","IE-LLOCA /SIT /LPI /HPR /HPH GCSRCTOP","",""
4,"2.855e-9","4","","IE-LLOCA /SIT /LPI /HPR GHSHBTOP /CSR /H2IG /CIS","",""
5,"5.178e-13","1","","IE-LLOCA /SIT /LPI /HPR GHSHBTOP /CSR /H2IG GCISTOP0","",""
6,"4.872e-10","5","","IE-LLOCA /SIT /LPI /HPR GHSHBTOP /CSR GH2IGTOP /CIS","",""
7,"","1","","IE-LLOCA /SIT /LPI /HPR GHSHBTOP /CSR GH2IGTOP GCISTOP0","",""
8,"1.544e-12","6","","IE-LLOCA /SIT /LPI /HPR GHSHBTOP GCSRCTOP /CIS","",""
9,"","2","","IE-LLOCA /SIT /LPI /HPR GHSHBTOP GCSRCTOP GCISTOP0","",""
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Fig. 4. Level 1 PSA Sequence Information

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"Sequence Information"
"SEQ#","PROB","STC #","CONSEQNCE","E_SEQUNCE","S_REMARKS","R_METRICS"
1,"0","","","","",""
2,"1","","","Events * NO BYPASS * NOT ISOLATED * NO FAILURE","","0"
3,"1","","","Events * NO BYPASS * NOT ISOLATED * FAILURE","","0"
4,"1","","","Events * NO BYPASS * ISOLATED * NO RCS FAILURE * MELTSTOP","","0"
5,"1","","","Events * NO BYPASS * ISOLATED * NO RCS FAILURE * RV RUPTURE * NO ALPHA * HIGH * NO EARLY CF * NO FAILURE * COOLED * NO LATE CF","","0"
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Fig. 5. Level 2 PSA Sequence Information

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PDS CET Fraction Table ------------------

CET	PDS#-1	PDS#-2	PDS#-3	PDS#-4	PDS#-5	PDS#-6	PDS#-7
CET#-1	1	0	0	0	0	0	0
CET#-2	0	1	1	0	0	0	0
CET#-3	0	0	0	9.50E-01	9.50E-01	0	9.00E-01
CET#-4	0	0	0	0	0	0	0
CET#-5	0	0	0	0	0	0	0
CET#-6	0	0	0	0	0	0	0
CET#-7	0	0	0	0	0	0	0
CET#-8	0	0	0	0	0	0	0
CET#-9	0	0	0	0	0	0	0
CET#-10	0	0	0	0	0	0	0
CET#-11	0	0	0	0	0	0	0
CET#-12	0	0	0	0	0	0	0
CET#-13	0	0	0	0	0	0	0

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Fig. 6. PDS-CET Fraction Information

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##### Combined Sequence #####
1 PDS Sequence Number: 2 PDS 37 X CET 98 2.251e-09 IE-LLOCA * /SIT * /LPI * /HPR * /HPH * GCSRCTOP * NO BYPASS * RBCM
2 PDS Sequence Number: 3 PDS 4 X CET 3 2.71225e-09 IE-LLOCA * /SIT * /LPI * /HPR * GHSHBTOP * /CSR * /H2IG * /CIS * NO BYPASS * ISOLATED * NO RCS FAILURE * MELTSTOP
3 PDS Sequence Number: 3 PDS 4 X CET 48 1.3737748955e-10 IE-LLOCA * /SIT * /LPI * /HPR * GHSHBTOP * /CSR * /H2IG * /CIS * NO BYPASS * ISOLATED * NO RCS FAILURE * RV RUPTURE * NO ALPHA * LOW * NO EARLY CF * NO FAILURE * COOLED * NO LATE CF
4 PDS Sequence Number: 3 PDS 4 X CET 51 3.5004840950000006e-12 IE-LLOCA * /SIT * /LPI * /HPR * GHSHBTOP * /CSR * /H2IG * /CIS * NO BYPASS * ISOLATED * NO RCS FAILURE * RV RUPTURE * NO ALPHA * LOW * NO EARLY CF * NO FAILURE * NOT COOLED * NO LATE CF * INTACT
5 PDS Sequence Number: 3 PDS 4 X CET 52 2.2015627315e-14 IE-LLOCA * /SIT * /LPI * /HPR * GHSHBTOP * /CSR * /H2IG * /CIS * NO BYPASS * ISOLATED * NO RCS FAILURE * RV RUPTURE * NO ALPHA * LOW * NO EARLY CF * NO FAILURE * NOT COOLED * NO LATE CF * MELTTHROU
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Fig. 7. Example of Generated Combined Sequences

Table I: Comparison of Number of Sequences

Initiating Event	Conventional Method (w/ grouping)	Proposed Method (w/o grouping)
CSGTR	21 (Number of source term category)	5
CSLOCA		575
GTRN		601
ISLOCA		1
LLOCA		329
LOCCW		795
LOCV		601
LODCA		601
LODCB		601
LOFW		601
LOKVA		795
LOOP		601
LSSB-INCTMT		1,510
LSSB-OUTCTMT		1,316
MLOCA		298
RVR		96
SBOR		1,807
SBOR2		1,678
SBOS		1,807
SBOS2		1,678
SGTR		15
SLOCA		575
TLOCCW		78
Total		16,964

4. Conclusions

In this study, the automatic source term generation algorithm has been developed and implemented for MAAP. The main functions of the algorithm are followings:

1) Read conventional level 1 PSA result: PDS-ET
2) Read conventional level 2 PSA result: CET
3) Read conventional PDS-CET coupling data
4) Generate the Combined Sequences
5) Generate MAAP input files

The developed and implemented algorithm can be used to investigate the uncertainty in PSA and improve the quality of PSA results.

REFERENCES

[1] C.H.Park and J.J.Ha, Probabilistic Safety Assessment, BrainKorea, Seoul, 2003.
[2] Fauske and Associates Inc, MAAP—Modular Accident Analysis Program for LWR Power Plants, Vols. 1 to 4, Electric Power Research Institute, 2008.
[3] Python Software Foundation. Python Language Reference, version 2.7. Available at http://www.python.org