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DEVELOPMENT AND APPLICATION OF PROBABILISTIC SAFETY ASSESSMENT PSA IN DAYA BAY NUCLEAR POWER STATION

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Abstract

This paper discusses the development and application of Level 1 PSA used for safety review, risk monitoring and on line maintenance of the nuclear power plant. PSA development includes the analysis of event tree, fault tree, FMEA, PSA quantification and the equipment reliability database.

We have collected and processed the reliability data of external power source, the equipment reliability data and the initial event frequency. The thermal-hydraulics analysis of some important events and accidents, human factor analysis, and the calculation of human error probability have been made. During the development of event trees and fault trees, the effect of some support systems such as compressed air distribution system, ventilation system and electrical system have been taken into account. The system manuals, operation procedures and emergency operating procedures of Daya Bay NPP are referred to in this project.

The operators of the NPP were involved in the establishment of all event trees and fault trees analysis. Furthermore, we have accepted the suggestion of IAEA experts, completed the logic chart of initial events to the initial events analysis of Daya Bay NPP, and optimized the code system of PSA model again. Together with the development of the reliability database, by absorbing the advanced experience of EDF, we have gained the reports about equipment's classifying, function and experience feedback information of Daya Bay NPP.

According to the quantitative calculation of the latest Level 1 PSA Model of Daya Bay NPP, the results of Core Damage Frequency (CDF) is: CDF = 2.13E-5/reactor • year.

The latest PSA Model of Daya Bay NPP includes:

（1） 12 sorts of initial events, 67 sub-initial events, 70 fault trees;
（2） 25 nuclear safety related systems were developed by fault trees and FMEA ;
（3） 2609 fault tree logic gates;
（4） 2146 basic events;
（5） 680 core damage accident sequences.

Key world: Probabilistic Risk Assessment, Equipment Reliability Database, Daya Bay Nuclear Power Station.

1. Introduction

Level 1 PSA of Daya Bay NPP, started in 1995, was completed in 1997 with the cooperation of Daya Bay NPP, Tsinghua University and Institute of Atomic Energy of China. In this stage, PSA mainly referred to France Level 1 PSA (EPS900) and the experience feedback of Daya Bay NPP as well. Based on the sensitivity analysis of practical condition of Daya Bay NPP, we carried out the PSA with the reliability parameters of EDF equipment. The second PSA work started at the end of 1997, and was completed mainly by the staff of Daya Bay

NPP and Ling Ao NPP. Safety analysis engineers, safety advisors on duty and some operators took part in the development of PSA projects. In addition, we retained professors of Tsinghua University to instruct our work. part of the work was undertaken by Nanhua University, Reactor Engineering Department of China Institute of Atomic Energy, Institute of Shanghai Nuclear Industry and Beijing Electric Power Academy of Sciences.

Compared with the first stage, this stage, with considerations of the operation condition of Daya Bay NPP, has made some modifications as follows:

- Establishing the living PSA of Daya Bay NPP and Ling Ao NPP, with the replacement of RISK SPECTRUM program for SETS program;
- Using PSA technology in NPP's operation, maintenance and special safety assessment;
- Modifying the main PSA reports;
- Making the calculation of the thermal-hydraulics based on the characteristics of Daya Bay NPP and the request of PSA;
- Making analysis and calculation of human reliability based on the results of thermal-hydraulics calculations and the accident regulations of Daya Bay NPP;
- Collecting the reliability data of Daya Bay NPP, and the reliability data of Guangdong and Hong Kong's power grid.

In addition, the PSA project team provides PSA training sometimes, and about 500 various technical personnel of Daya Bay and Ling Ao NPP attended nearly 20 training courses. We have made some applications and developments of PSA technology in NPP's modifications, operation safety assessments and maintenances, and developed the Plant Equipment Reliability Data (PERD), Plant Online Risk Monitor RISK MONITOR system etc.

2. Level 1PSA of Daya Bay

In order to make the living PSA model of Daya Bay, we collected and analyzed the reliability data of external power source, the reliability data of equipment and the initial event frequency. We also have made thermal-hydraulics analysis, human reliability analysis, and the calculation of human error probability which has been involved in the event trees and fault trees analysis. During the development of event trees and fault trees, we have taken into account the effect of some support systems such as compressed air distribution system, ventilation system, electrical system and so on. We started the project from system manuals, operation procedures and emergency operating procedures of Daya Bay NPP. The operators of NPP took part in the development of all event trees and fault trees analysis, and we have completed the Failure Model and Effect Analysis (FMEA) for every fault tree. Furthermore, we have accepted the suggestion of IAEA experts, and completed the logic chart of initial events to impose the initial events analysis of Daya Bay NPP and to optimize the code system of PSA model again. We integrated the development of reliability database, absorbed the advanced experience of EDF, then made out the reports of equipment classifying, function and experience feedback information of Daya Bay NPP. According to the quantitative calculation of the latest Level 1 PSA Model of Daya Bay NPP, the results of Core Damage Frequency (CDF) is:

$$CDF = 2.13E\text{-}5/\text{reactor} \bullet \text{year.}$$

The latest PSA model of Daya Bay NPP includes:

- 12 sorts of initial events, 67 sub-initial events, 70 fault trees;
- 25 nuclear safety related systems to were developed by fault trees and FMEA;
- 2609 fault tree logic gates;
- 2146 basic events;

- 680 core damage accident sequences.

2.1 PSA Model Initial Events of Daya Bay NPP

The initial events in the PSA model of Daya Bay NPP are mainly internal ones of NPP, and the external ones, such as earthquake, fire and typhoon etc, will be considered in later PSA analysis. In addition, there will be more detailed analyses of the initial events of reactor trip condition.

The initial events of Loss of Coolant Accident (LOCA) have 4 types: Large LOCA, Middle LOCA, small LOCA and Reactor Vessel Rupture.

Other transient initial events include 12 types as follows: Loss of Heat Sink, Loss of Feedwater, Loss of Offsite Power, Anticipated Transients Without Scram (ATWS), Steam Line Break, Boron Dilution, Loss of DC Sources, Steam Generator Tube Rupture (SGTR), SGTR+ Steam Line Break (SLB) Steam Generator Tube Rupture and Secondary Side Line Break.

2.2 Predominate Equipment of Daya Bay NPP

According to the PSA Model of Daya Bay, after quantitative calculation by RISK SPECTRUM, the 12 equipment faults making the predominant effect for the risk of core damage have been found, and they are: diesel generator group's faults, steam turbine's faults of auxiliary feedwater system, common cause failure (CCF) of water level sensor of Refueling Water Storage Tank (PTR)tank, inlet and outlet valves faults of Component Cooling Water System (RRI) and Residual Heat Removal System (RRA), faults of reactor emergency shutdown system, steam turbines' faults of water pressure testing pumps, pumps' CCF of safety injection system, two pumps' CCF of RRA, pumps' fault of RIS, CCF of motor operated suction valves of RRA, CCF of motor operated discharge valves of RRA and heat exchangers' faults of RRI etc..

2.3 Results of Level 1 PSA of Daya Bay NPP

The results of level 1 PSA of Daya Bay are listed as below:

CDF of All Initiators and Plant State in Level One PSA of Daya Bay NPP

Initial Event		CDF				Sum of CDF (1/RY)		Fraction %	
		A	B	C	D				
Primary Pipe Break (LOCA)	LLOCA	2.24E-07	1.89E-09	4.97E-07		7.23E-07	7.27E-06	3.39%	34.15%
	MLOCA	9.15E-07	8.82E-09	9.61E-07		1.88E-06		8.83%	
	SLOCA	3.53E-06	4.61E-07	2.25E-07	2.19E-07	4.43E-06		20.80%	
	Reactor Vessel Rupture	2.40E-07				2.40E-07		1.13%	
Loss of Heat Sink		3.76E-07			1.63E-06	2.01E-06		9.44%	
Loss of Feed Water		1.48E-06	4.21E-07			1.90E-06		8.92%	
Loss of Offsite Power		2.20E-06	2.25E-06	9.54E-08	2.80E-09	4.54E-06		21.31%	
ATWS		9.74E-07				9.74E-07		4.57%	
Secondary Line Break		8.72E-07	9.95E-09			8.82E-07		4.14%	
Boron dilution		3.12E-07			3.21E-07	6.33E-07		2.97%	
Loss of DC Source		3.01E-07				3.01E-07		1.41%	
SGTR		2.02E-06				2.02E-06		9.48%	
SGTR+SLB		7.85E-07				7.85E-07		3.69%	

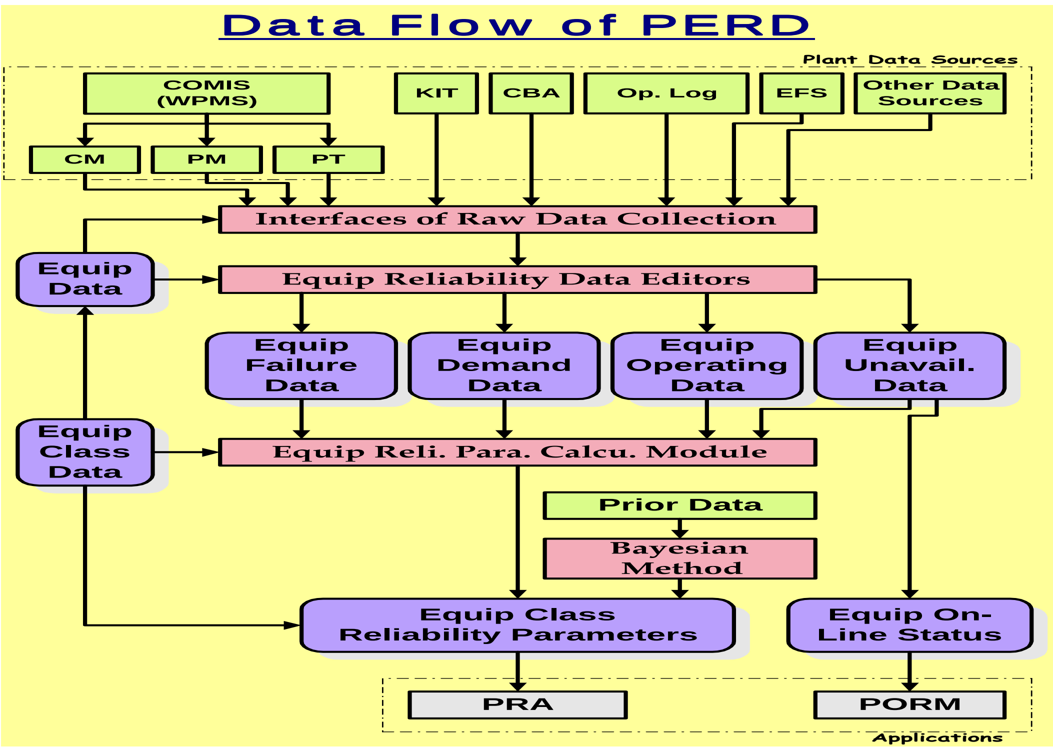
Secondary transitions	2.80E-08				2.80E-08	0.13%
Scram	3.92E-09				3.92E-09	0.02%
Sum of CDF	1.43E-05	3.15E-06	1.78E-06	2.17E-06	2.13E-05	100.00%
Fraction %	66.95%	14.80%	8.35%	10.20%	100.00%	100.00%

3. Nuclear Power Plant Equipment Reliability Database

Nuclear Power Plant Equipment Reliability Database (PERD) is an important information system in Daya Bay NPP. All of the data collection and transmission are processed through local-area network (LAN) automatically. The database can supply not only the historical operation records and original characteristic parameters of plant's equipment, but also the equipment failure trend analysis and reliability parameters of those equipment. There are 115 classes of equipment, about 2000 components/unit in PERD including all equipment on which Level 1 PSA was processed. The scale and capability of database can be freely extended and increased along with the need of plant's work so that we can add the new equipment types and components into this database.

The main purpose of developing PERD is to improve the level of NPP safety and equipment management, and supplying basic reliability parameters of plant's Level 1 PSA, On-line Risk Monitor and Reliability Centered Maintenance (RCM). Meanwhile, it can supply valuable data for plant's safety assessment, preventive maintenance, corrective maintenance, management optimization spare parts, and also it serves for operation and maintenance.

The detailed construction and relationship among different parts of database are listed as below:



The main data sources of equipment described in above chart includes:

-KIT system:

KIT system is the brief term of Centralized Data Processing System which records various kinds of sensor signals on time. There are 4500/unit switch variables and 1500/unit anolog variables in KIT.

-COMIS system:

COMIS system is the brief term of Company Operation & Maintenance Information System which supplies data such as equipment failure data, maintenance data, testing invaluable data, planning unavailable data, operating data and demanding data and so on.

-CBA system:

CBA system is the brief term of Computerized Blocking Assistant, it supplies blocking information and equipment boundary.

-EFS system:

EFS system is the brief term of Experience Feedback System. It is mainly used for collecting fault data of equipment. EFS system and corrective maintenance records are the main sources of equipment fault data in equipment reliability database. EFS system records such information as the occurring time of plant's various operation events, the reason analysis, the effect to system/units/operation, the measure, and the results etc. These data are important complements for equipment data.

-Other data sources:

Other data sources of equipment reliability database includes those data coming from EDF "hot line", and from relevant plants.

4. Plant Online Risk Monitor System

The visual risk analysis software of Daya Bay NPP, Plant Online Risk Monitor (RISK MONITOR), has made the real project chart as main interface, and the user can slowly go deep into each part system, sub-system and supporting system. Through making a system reliability analysis, we have built a corresponding system reliability model on the base of system charts. Moreover, we integrate the technology of FMEA and FTA into the same software system, which makes the software have the characteristics of quite high intelligence and expert system.

Visual software, RISK MONITOR can automatically collect and process the data of system and equipment conditions of NPP on time. With rapid PSA calculation, we can gain the real time risk value of NPP, and supply a powerful decision-making reference function for guaranteeing reliable running of NPP. The operatinging, maintaining and managing staff can know the effect of their operation on system and plant's safety by risk monitor, and they can judge and forecast the possible events frequency of NPP, and realize the real NPP condition. Furthermore, the reliability and safety of NPP can be improved greatly, and the number of unplanned shutdown will be reduced, so the availability and economic benefit will be improved as well.

The main functions and characteristics of RISK MONITOR are listed as below:

•This system has the ability to build fault trees automatically. It can integrate the following functions into a system: system charts edition, fault trees logic edition, database maintenance, mutually querying and managing user, so that we can make those different information type, including system chart, fault trees logic, equipment data and fault frequency data etc., associating with each other;

• This system uses relational database as the support of bottom data management; uses open data interface to connect with large database Plant Equipment Reliability Database (PERD); support the mutual inquiry for system on line chart, fault logic chart and database. The inquiry measure is completely visual and graphical.

• The possible risk and effect caused by the invalidation of equipment and systems can be inquired directly in system charts, and the risk can be displayed in the system's main interface directly. Furthermore, the system can give corresponding measure, the analysis curve of system reliability and risk, and the analysis risk list.

• Risk Achievement Worth (RAW) and Allowed Outage Time (AOT) of NPP can be calculated through the system of RISK MONITOR

The system of RISK MONITOR of Daya Bay NPP uses the real project chart as the main interface to activate project flow chart, and slowly goes deep into each part system, sub-system and supporting system. Through system reliability analysis, we have built corresponding system reliability model on the base of system charts. Moreover, we integrate the analysis technology of FTA and FMEA, in which the effect for system itself and other relevant systems after certain equipment being fault is analyzed, into one software system, which makes the software have the characteristics of quite high intelligence and expert system. In addition, RISK MONITOR can supply units' risk information, remind staff that risk may exist anywhere anytime, and supply the results of FMEA analysis which can help staff analyze risk.

The system of RISK MONITOR can automatically collect the data of systems and equipment conditions of NPP on time, and process them as well. By rapid PSA calculation, we can gain the real time risk value of NPP, and supply powerful decision-making reference function for guaranteeing reliable operation of NPP. The running, maintaining and managing staff can know the effect of their operation on the system and plant's safety by risk monitor, and they can judge and forecast the possible event frequency of NPP, realize the real NPP condition, and optimize the repairing plan depending on risk condition. Furthermore, the reliability and safety of NPP can be improved greatly, the number of unplanned shutdown will be reduced, so the usability and economic benefit will be improved as well. In a word, the visual software risk monitor develops a wider foreground for the application of PSA technology in guaranteeing reliability and safety of NPP's running.

5. Conclusion

The development and application of PSA technology is a new field. It becomes more and more important for us to use PSA in safety analysis and maintenance optimization of NPP. As an assessment tool for NPP, PSA will be developed in high speed. Over 6 years, efforts in this field has laid a good foundation for operation safety management and maintenance. It can be seen that PSA technology will be used widely in Daya Bay NPP.

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