Development of reliability data analysis system in nuclear power plant

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Abstract: The conductance of probabilistic safety assessment (PSA) and reliability centered maintenance require a huge amount of data collection, analysis and application work, where quality of safety assessment would depend not only on the programming of data algorithm but also on the screening of the collected data. An online treatment and storage system of reliability data has been developed in this study for the acquisition, calculation and accumulation of reliability data that can be used in various applications of plant engineering as well as for the probabilistic safety assessment in nuclear power plant (NPP). The system gathers the specific data of NPP such as operation data, maintenance history and shift diary of the operator from the Digital Instrument & Control System to achieve its online function. The collected data are stored in a special database after the process of examining and classifying. The reliability calculation is based on Bayes inference method which combines with *a priori* information and *a posteriori* information so that the reliability data is calculated and updated in time to make it more accurate and reliable than before. The system consisting of a huge database, a data collection module and a reliability data model can be established based on system engineering and management method, and for the application of this system, reliability data of the NPP can be transferred to Living PSA model to compute the instant and average risk. The long-term storage of the reliability data also becomes the foundation of reliability-centered activity so that it makes possible for users to comprehend the present state and to predict the trend of the reliability information related to the equipment and component in the NPP. The proposed system will contribute to reinforce the wide use of PSA to provide an integrated system that offers all the information needed for the PSA from the basic plant data to the customized reliability data.

Keyword: probabilistic safety assessment (PSA); reliability centered maintenance; online treatment and storage of reliability data

1 Introduction

Nuclear safety has always been a foothold and lifeline of nuclear power plant operation. The target that engineers pursue is to make the nuclear power plant operate safely and economically. After the Fukushima nuclear accident, Chinese government has changed the nuclear power development policy from active development to proceed with caution. In order to meet with this political requirement an innovative idea of online risk monitor and risk management system will be introduced into the operation and management of nuclear power plant [1]. By monitoring the operation configuration of the nuclear power plant equipment and its change, the instantaneous risk and average risk is calculated. The result can be used to optimize operation and maintenance decision-making and improve the safety and economy of the nuclear power plant. In order to calculate the risk level of nuclear power plant, evaluate the reliability and safety and realize the optimization management of nuclear power plant, reliability data of equipment needs to be the foundation of the analysis. In the design, construction, operation and safety analysis of nuclear power plant, it involves a lot of data acquisition, processing, analysis and application work. The results of the design calculation and safety analysis depend not only on the model and the calculation program, but also on the accuracy of the input data.

At present, the collection, analysis and storage of the reliability data[2] have made some progress. Currently reliability data collection can only be made by manually inputting the equipment running, condition and operation data into the computer. It cannot directly transfer to the nuclear power plant information system automatically and cannot identify the data's authenticity, so the data accuracy is poor. The reliability parameters obtained from the sample information is a complicated calculation procedure.

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At present, the reliability parameters of the mainstream commercial reliability analysis software are based on the life of the equipment follows the exponential distribution. The advantage of this method is that the analysis and calculation are simple, but the disadvantage is that the reliability parameters cannot be estimated accurately. In the field of nuclear industry, the reliability of the equipment is generally so high that the failure of the equipment and the frequency of the abnormal events are pretty low. It is good for the industry. But the scant occasion of reliability data acquisition faces methodological difficulties since long time accumulation of equipment reliability data can have statistical significance so that the estimated reliability parameter will be more accurate, which can provides basic data for probability theory centered activity in nuclear power plant[3].

The objective of this paper is to introduce a process and system for the reliability analysis and processing of nuclear power station. The system is defined as a database application system for the use of reliability data analysis in nuclear power plant. It can realize the function of reliability data and parameter acquisition, calculation and storage in the real environment of nuclear power plant.

2 Requirement analysis

Requirement analysis is the basis of system engineering, and it is also a basic tool in the field of nuclear safety and reliability. The purpose of the analysis is to guarantee the completeness and reliability of the system development.

2.1 User analysis

Because of the nature of this work, the user of the system can be divided into ultimate user, professional user, system analyst and application programmer as shown in Fig. 1. Those four types of users of the system will be as mentioned below.

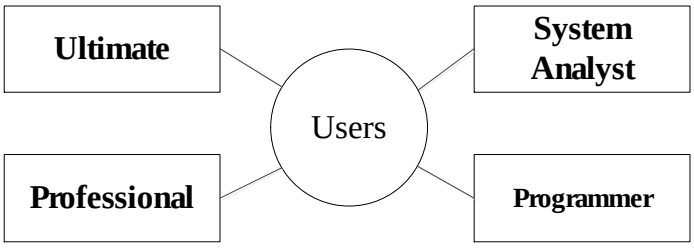

Fig.1 Users of the system.

(1) "Ultimate" means the ultimate users of the real system. They always do not have an access to edit the data in the system. They are supposed to obtain initial event frequency, human error probability and reliability data. And the initial event frequency and the human error probability can only be updated manually.
(2) Professional user is a kind of people who has specialized knowledge. This kind of user is expected to input the manual data, validate the collected data and make expanded use of the reliability.
(3) System analyst is in charge of the demand analysis and system design. Their work includes establishing the database, developing the application system and maintaining the system.
(4) The application programmer is to develop the professional application program, which will support all users' service.

2.2 Function analysis

This system requires three major functions. The first is to provide reliability parameters for online risk monitor, such as failure rate of the equipment, the demand failure probability, *etc*. The second function is reliability data accumulation in the whole life of nuclear power plant. The third is the expanded application for life extension.

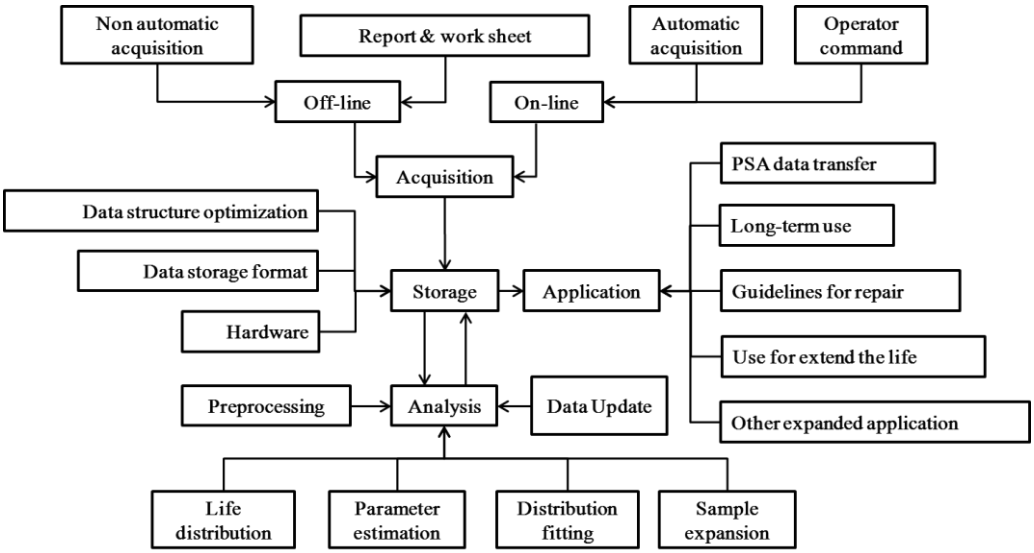

Fig.2 Functional framework diagram.

In order to accomplish the above three functions, the modules of the system are composed by acquisition, analysis and storage. Figure 2 describes the functional framework of the system to be developed.

2.3 Performance analysis

The performance of the system shall meet with the following requirements:

(1) Data capacity

The reliability data of nuclear power plant equipment are statistically analyzed based on the device class. There are about 150 device classes in the plant. We set the maximum number of the device class is 300. And we assume that each device class has maximum 100 samples. So the largest installed capacity of the system is 30000.

(2) Database growth rate

The basic information of the equipment in the system is updated according to the current state of the nuclear power plant. There will be a little difference between each sample equipment operation life data. The updating frequency of reliability parameters combines time based and require based method.

(3) Network and shared access requirements

To ensure the reliability of the system, the server should carry redundant. Two separate servers are set up to guarantee the mutual capabilities of backup and correction.

3 Data analysis

The contents of the stored data contained in the system include equipment basic information, failure data, running parameters, reliability parameters of each failure mode, *etc*. Data is the foundation of this system.

3.1 Data Dictionary

The data stored in the database is first explained with the specific data structure as shown in Table 1. There are many kinds of data in nuclear power station. The relationship between different kinds of data constitutes the structure of the system. The E-R (Entity Relationship) diagram[4] as illustrated in Fig. 3 reflects the relationship between the data. There are three types of co-relationship in the E-R diagram. They are one-to-one (1:1), one-to-many (1: n) and many to many (m: n).

Table 1 Data structure

No.	Name	Data Type	Record length
1	Device class name	Char	30
2	Device class code	Int	10
3	Boundary description	Char	100
4	Environment description	Char	300
5	Failure mode description	Char	300
6	Environment factor	Float	4
7	Device class code	Int	10
8	Device code	Int	10
9	Device state	Int	2
10	Start working time	Int	10

11	Stop working time	Int	10
12	Start repairing time	Int	10
13	Stop repairing time	Int	10
14	Failure count	Int	4
15	Demand count	Int	4

The data stored in the system is composed of a group of data tables, where roughly speaking, the following definitions are employed;

- System data = [Basic data of equipment | equipment code table | failure mode table | operation parameter table | failure mode record table | reliability data table | general data table]
- The device code table = equipment class code + equipment code + equipment name
- The equipment basic information table = equipment code table + boundary description + production information + working environment + correction factor
- The failure mode table = equipment code table + failure mode name + failure mode description + failure hazard + common cause failure description
- The failure mode record = equipment code table + failure mode record
- The operation parameter table = equipment code table + working state + work start time + work end time + test start time + test end time + maintenance start time + maintenance end time
- Reliability data table = equipment code table + equipment failure rate + equipment availability.

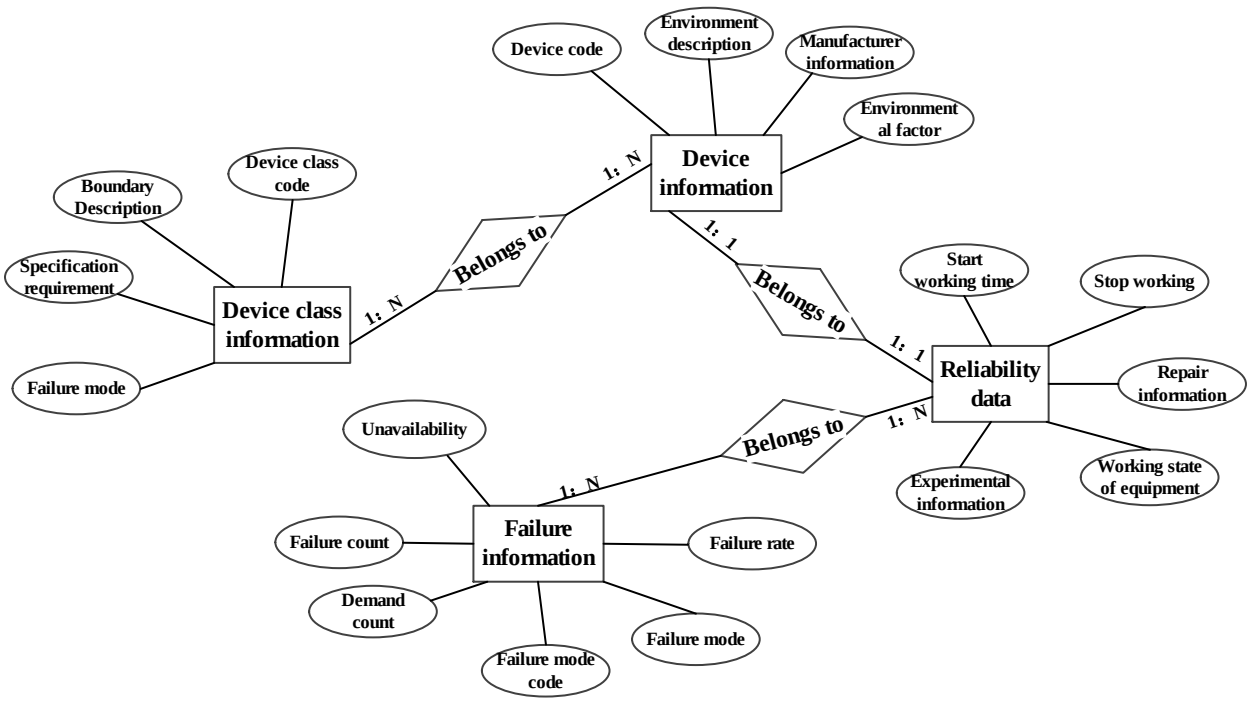

Fig.3 E-R diagram.

3.2 Data flow diagram

The data flow in the system constitutes the data flow chart of the system. Data flow chart is the important basis for system programming. It not only reflects the trend of data in the system, but also reflects the data processing process. Figure 4 is the system data flow chart.

3.3 Mathematics analysis

The data stored in the system need to be analyzed and processed to obtain the reliability parameters. The nature of failure data of the equipment in nuclear power station is very complicated one[5] because of several reasons:

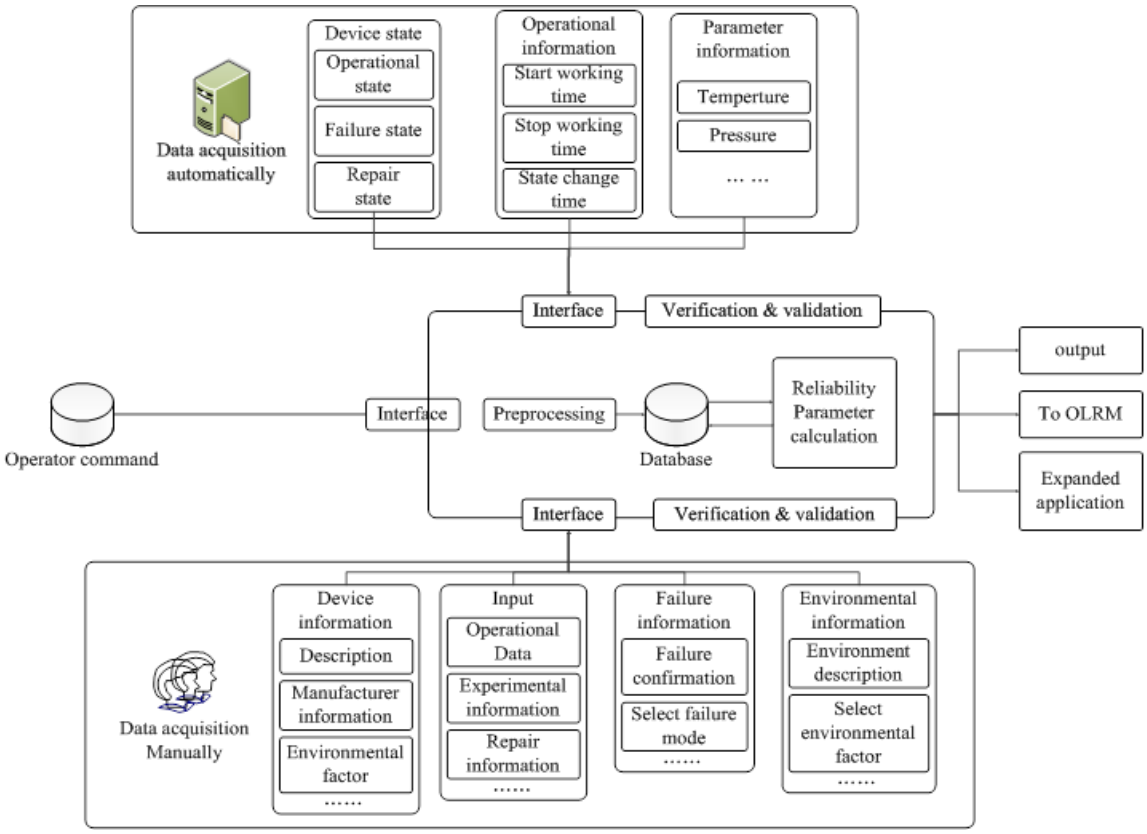

Fig.4 Data flow chart.

Firstly, the failure mechanism of the mechanical equipment is so complex that it is difficult to express it accurately; secondly, the reliability of the equipment is so high that the failure data is difficult to collect; and finally, the analysis and processing of data need a lot of mathematical calculations.

In order to solve the problem of lack of data, the Bayesian inference method [6] is usually used to deal with the problem of small sample when the reliability data is calculated. At the same time, in order to improve the precision of calculation, we usually use the Weibull distribution to describe the lifetime of equipment [7]. The calculation steps by the Bayes inference method employed in this study are shown in Fig. 5. It is said that prior distribution is the most important part of the Bayes inference method. The prior data are usually derived from the general database. General database is established by experienced engineers of nuclear power plant or nuclear power plant equipment manufacturer. General data cannot reflect the specific feature of the power plant, but it is used as the way of compromise.

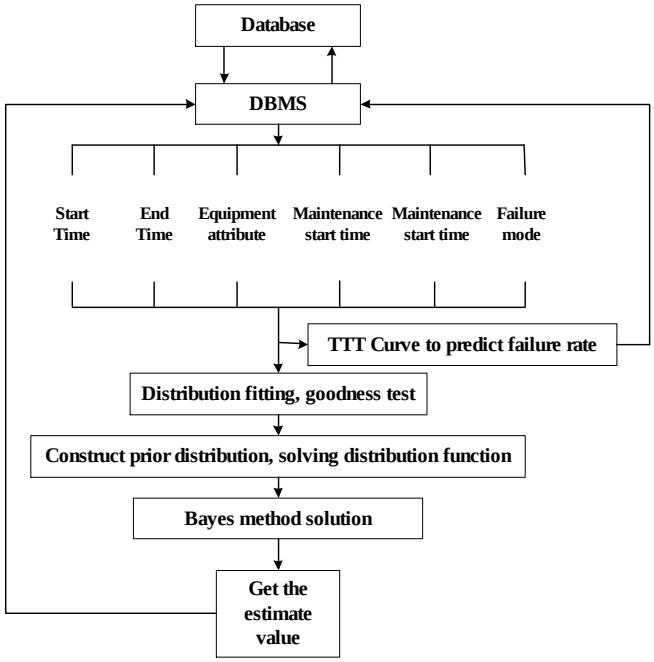

Fig.5 Employed bayes inference mthod.

Figure 6 shows the basic process of the data in the system. The reliability data is statistically processed in accordance with the difference of operation failure and demand failure[8].

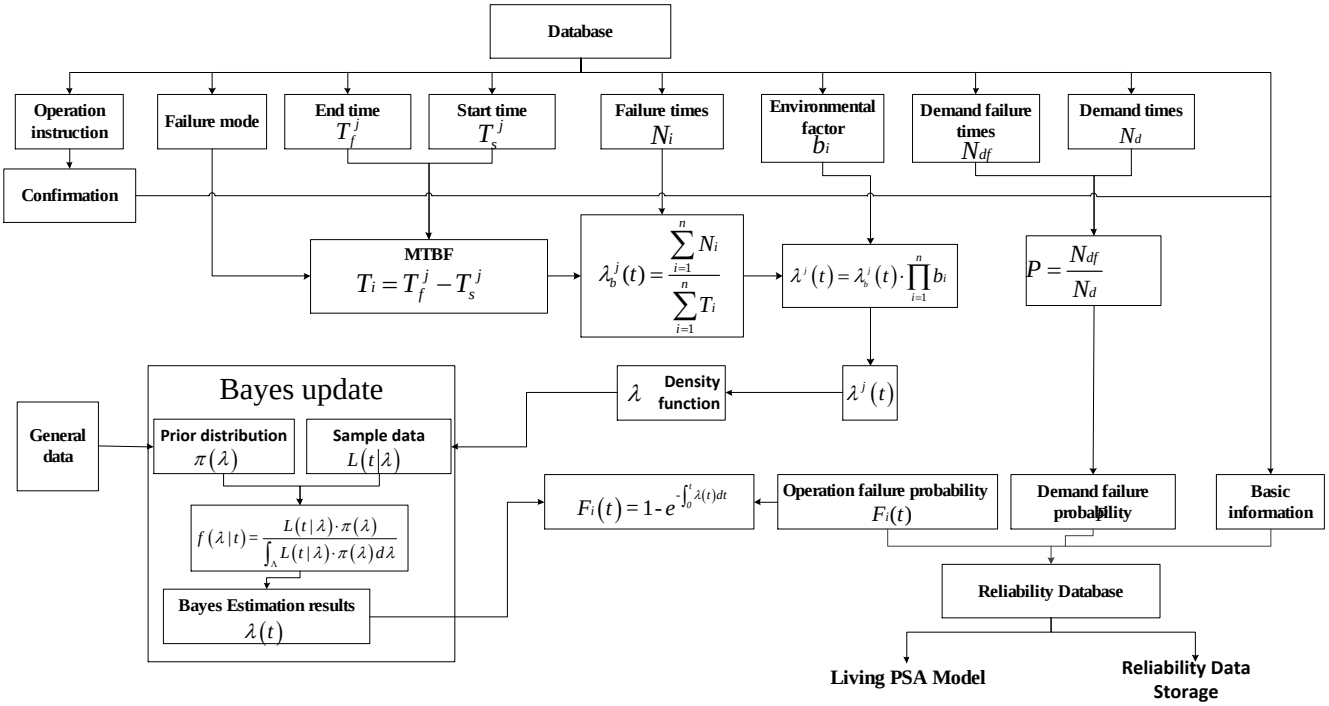

Fig.6 Data processing

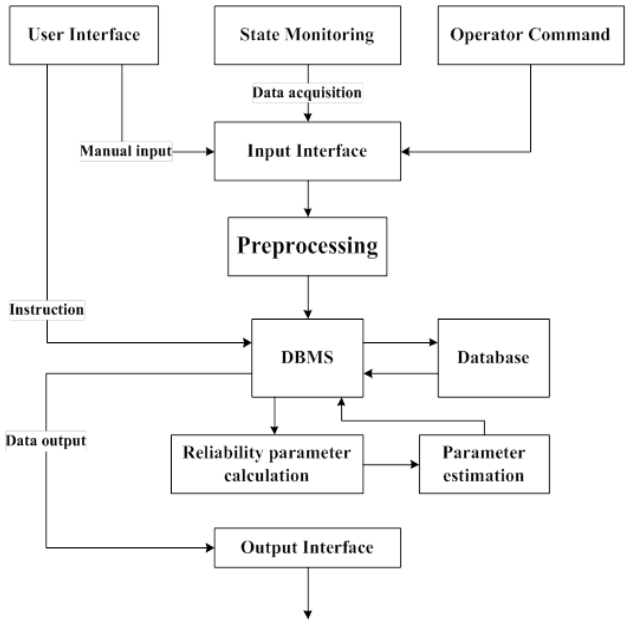

Fig.7 System structure.

4 Conceptual design

According to the above analysis, the system structure diagram can be designed as follows:

Data acquisition is divided into automatic collection and manual collection. Under the condition of DCS system, partial data acquisition can be realized automatically [9]. This part of the data includes information on the operation parameters and running time of the equipment. During the operation of nuclear power plant, some data cannot be collected automatically. This part of the data includes the basic information of the equipment, failure mode information, *etc.* In addition, the operator's command information is also the scope of the acquisition. The operator's command information can provide the basis for data discrimination.

The modules are designed to achieve the above functions by considering the following items such as;

- User management,
- Reliability data acquisition,
- Reliability data report,
- Initial event frequency,
- Human error,
- Common cause failure,
- Device class, and
- Conventional data.

Above is the preliminary design method of the system. This design method will guide the system development and is the basis of coding

5 Conclusion

The conductance of PSA and reliability centered maintenance require a huge amount of data collection, analysis and application work, where quality of safety assessment would depend not only on the

programming of data algorithm but also on the screening of the collected data. An online treatment and storage system of reliability data has been developed in this study for the acquisition, calculation and accumulation of reliability data that can be used in various applications of plant engineering as well as for the probabilistic safety assessment in nuclear power plant (NPP).

The system intended by this study can gather the specific data of NPP such as operation data, maintenance history and shift diary of the operator from the digital instrument and control system to achieve its online function. The collected data are stored in a special database after the process of examining and classifying. The reliability calculation based on Bayes inference method will combine *a priori* information with *a posteriori* information so that the reliability data is calculated and updated in time to make it more accurate and reliable than before. The system consisting of a huge database, a data collection module and a reliability data model can be established based on the system engineering and management method, and for the application of this system, reliability data of the NPP can be transferred to Living PSA model to compute the instant and average risk. The long-term storage of the reliability data will also become the foundation of reliability-centered activity so that it makes possible for users to comprehend the present state and to predict the trend of the reliability information related to the equipment and component in the NPP.

The purpose of this system is to evaluate the reliability of nuclear power plant equipment, and to estimate the failure trend. The system will provide reliable data for online risk monitor and make contributions to the cumulative use of reliability data in plant operation and management. In the future, it can also be applied for nuclear power plant life extension.

This paper begins with the analysis of the requirements and analyzes the needs of the system, and end up with the presentation of the method and process of data processing as the conceptual design of the system which will give the basis of system development to affect the whole product development and use process.

When the proposed system is realized, it will contribute to reinforce the wide use of PSA to provide an integrated system that offers all the information needed for the PSA from the basic plant data to the customized reliability data.

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