Analysis of Fire Consequences of Hua-Long One Nuclear Power Plant

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Abstract. Fire is one of the internal disasters that must be considered in nuclear power plants. The consequence analysis of nuclear power plant fire provides design input for the programming of fire accident treatment by analyzing the influence of regional fire on the safe and stable operation of the unit. The design of the third generation PWR nuclear power plants in China puts forward higher requirements for fire consequence analysis. According to the practical engineering application of fire consequence analysis method in Hua-long No.1 nuclear power plant, this paper introduces the fire accident design standard, fire consequence analysis content and intelligent fire consequence analysis exploration of Hua-long No.1 unit. Through the introduction of this paper, this method is extended to the subsequent fire consequence analysis of Hua-long No. 1 unit or other third-generation nuclear power plants.

Keywords: Fire · Hua-long One · Impact and Consequence analysis · Intelligent

1 Introduction

Fire is an internal disaster with relatively high frequency in nuclear power plants [1]. Because of the regional destruction characteristics of fire, the fire is often accompanied by the spreading nature, resulting in burning and high temperature in the region. Therefore, the fire accident not only causes the complex transient of the unit, but also leads to a large number of instrument and control cabinet failures, damage of control and power cables, and unavailability of safety-level equipment, all of which will cause false triggering of a large number of alarms of the unit, making it difficult for operators to correctly judge the state of the unit and then alleviate the accident. Therefore, it is necessary to analyze the fire consequences of the unit and identify the impact of the regional fire on the unit, which is of positive significance to help the operator withdraw the unit from the fire accident state to the safe shutdown state [2]. In the prior art, the focus of fire consequence analysis is to analyze the influence of important safety equipment and functions of the unit caused by fire accidents, but the influence analysis of important safety signals of the unit and necessary information for executing post-accident treatment procedures of the unit is lacking. The faults of these important information, including false alarm

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and false information display, all lay the hidden trouble of false diagnosis and wrong operation for operators in the process of dealing with the accident, which is extremely unfavorable to the accident mitigation after the fire [3]. The fire consequence analysis method mentioned in this paper makes up for this defect to some extent.

In addition, the intelligent analysis and control of nuclear power plant accident conditions is the main direction of nuclear power plant operation control in the future, and the intelligent research of nuclear power plant fire consequence analysis is also an important research direction of intelligent nuclear power. This paper also discusses this part.

2 Impact Analysis of Fire Accident

The fire accident in nuclear power plant will be alerted by the fire detection system or witnesses on the spot. For the fire that can be extinguished by local fire-fighting facilities (such as fire extinguishers) or quickly extinguished by the secondary fire brigade of the power plant, the unit does not need to enter the accident operation control unit. For the accident that can't be eliminated after the first human intervention, the fire accident is confirmed.

The confirmed fire accidents can be divided into the initial fire accident and the post-accident fire accident according to the timing of the fire accident.

2.1 Impact of the Initial Fire Accident

As the initial event of fire, according to the internal disaster protection design of nuclear power plant, it will only lead to some transient working conditions. Depending on the severity of its consequences, it will have different influences on the control of unit operation state, which can be divided into the following categories:

When a fire causes the loss of a single device, the loss of the device may affect a certain safety function. This situation can be managed within the normal operation scope without being included in the accident treatment category; When the fire causes some equipment or equipment control loss and then causes transient, the fire may cause some unexpected transient. If the valve is closed or opened by mistake after the control cable is damaged by fire, whether it needs to be managed by the Emergency Operation Guide (EOR) should be judged according to the specific transient consequences;

When the fire causes the loss of support function, including the loss of electricity, gas and cold source caused by the fire, it will need to be managed by EOR, because the loss of support function is considered as a kind of event in the accident operation guideline system. Therefore, if the fire causes the loss of support function, it may need to be managed by EOR;

When the fire causes the loss of NSSS function and then causes an incident or accident transient, the fire may cause the loss of a certain NSSS function and then develop into an incident or accident transient beyond the scope of normal operation management. Such situations need to be managed by EOR;

When the reactor is shut down due to fire, there are many reasons for the shutdown. On the one hand, the fire may directly damage the relevant instruments of the protection

channel and make the protection system operate, resulting in reactor shutdown; On the other hand, the fire may cause some NSSS functions to lose and some system parameters to deteriorate, resulting in reactor shutdown signal. For example, after the fire causes leakage isolation, the reactor shutdown will be triggered by the high water level signal of the pressurizer. It is also possible that the fire directly damages the shutdown devices. At the same time, the fire may cause the shutdown circuit breaker to open directly and shut down the reactor. As one of the entry conditions of the emergency operation guidelines, the reactor shutdown signal is required to enter the emergency operation guidelines to manage the state of the unit.

When the fire causes the loss of related instruments such as unit condition monitoring, the fire may directly damage the instruments or instrument cables, making the relevant parameter signals unavailable, affecting the operator's judgment on the unit condition, and further affecting the guidance of the accident operation guidelines.

2.2 Impact of Post-accident Fire Accident

In case of a long-term fire after the accident, the special safety facilities required to alleviate the accident have been put into operation automatically or manually, and the unit is already in the accident operation condition. The fire will not hinder the operation of the equipment or safety functions required to alleviate the accident, but the fire may damage the relevant unit condition monitoring or accident monitoring instruments, and affect the diagnosis of the unit condition during the accident treatment.

For some fire accidents that affect the power supply system of active equipment of safety functional equipment, operators are required to switch the operating safety functional equipment to the standby train or use other accident treatment strategies.

3 Content of Fire Consequence Analysis

According to the protection design standard of nuclear power plant, nuclear power plant fire consequence analysis confirms the functions and information required by the unit in case of fire accident, and guides the equipment affected by fire accident to set fire protection.

3.1 Standard Criteria of Fire Protection Design

Considering the probability and consequences of transients, <design and construction rules for system in PWR nuclear power plants > (RCCP-95) divides the operating conditions into four categories: normal operation and anticipated transients (Category I), medium frequency events (Category II), infrequent accidents (Category III) and limiting accidents (Category IV) [4].

According to the universal protection criteria, it is confirmed that the regional fire accident will not lead to the failure of the safety functions required to retreat to the safe shutdown state in case of unit accident. At the same time, internal fire will not cause the design basic accidents (Category III and IV conditions) listed in final safety analysis report (FSAR). The internal fire protection of nuclear power plants should meet the following design standard:

– It is assumed that the nuclear power plant fire occurs under normal operation and anticipated transients (Category I) or after the design basis accident (Category II) reaches a controllable state, or after the design basis accident (Category III and IV conditions) reaches a safe shutdown state, or 15 days after the over-design basis accident (DEC) occurs;
– Two or more independent fire incidents occurring in the same or different plant buildings at the same time are not considered. At the same time, fire and independent internal and external events are not considered to happen at the same time;
– According to the spread characteristics of the fire accident, all equipment in the fire zone where the fire broke out (except that it is protected by a fire barrier with sufficient fire resistance or has sufficient fire resistance) shall be regarded as lost;
– All fire protection equipment and systems (such as fire zone boundary, automatic fire alarm system and fire extinguishing system) that protect safety functions shall be set to safety level; The random failure of the active equipment in the fire protection system should not lead to the failure of the safety functions required to ensure the evacuation of the unit to a safe shutdown state in the event of a fire accident.

3.2 Scope of Fire Consequence Analysis

Hua-long one nuclear power plants implement thorough fire zoning for nuclear island, that means all buildings in nuclear island are separated into different fire zones. Fire zoning aims to prevent a fire from spreading into the rest of the same building within a certain period of time, so as to physically limit the consequences of the fire.

According to the fire protection design standard and the analysis of the impact of fire on the unit, the fire consequence analysis should be aimed at the workshop where the equipment and cables related to the safety level system are arranged, and the fire zone should be taken as the minimum analysis unit. According to the actual engineering application, among the factories to be analyzed, there are situations where fire zones of evacuation passageway (ZFA), unsafe fire zone (ZNS), safe fire zone (SFS) and safe fire zone (ZFS) are arranged in a cross way. However, according to the principle of fire zone setting of Hua-long No.1 unit, appropriate fire protection measures have been taken for safety-related equipment and cables in ZFA and ZNS. Therefore, the fire consequence analysis is limited to SFS and ZFS in the corresponding plant [5].

3.3 Methods of Fire Consequence Analysis

The object of fire consequence analysis is the guidance information used in accident treatment. Through the analysis of fire consequences, the influence of fire in fire zones on the information necessary for the unit's emergency operation is sorted out [6].

The function and support function of nuclear steam supply system (NSSS). Sort out the NSSS function list, support function list and corresponding component equipment information at the unit-level. By collecting the equipment information and cable information (without fire protection) in the fire zone, the corresponding equipment information is sorted out. By comparing the equipment information in the fire zone with the equipment corresponding to the unit-level NSSS function list and support function list,

we can sort out the NSSS functions and support functions affected by the fire accident in this fire zone.

Guidance information necessary for EOR. According to the accident operation procedure, sort out the list of information necessary for EOR, and list the sensors and valve information corresponding to the information. At the same time, it is also necessary to sort out redundant alternative signals or devices of corresponding signals. By collecting the equipment information in the fire zone and cable information (without fire protection), the corresponding sensor and valve information is sorted out. By comparing the information of sensors and valves affected by fire zone with the information of sensors and valves corresponding to the list of information necessary for EOR. When redundant measuring sensors lose one or part of their columns, signal logic degradation should be

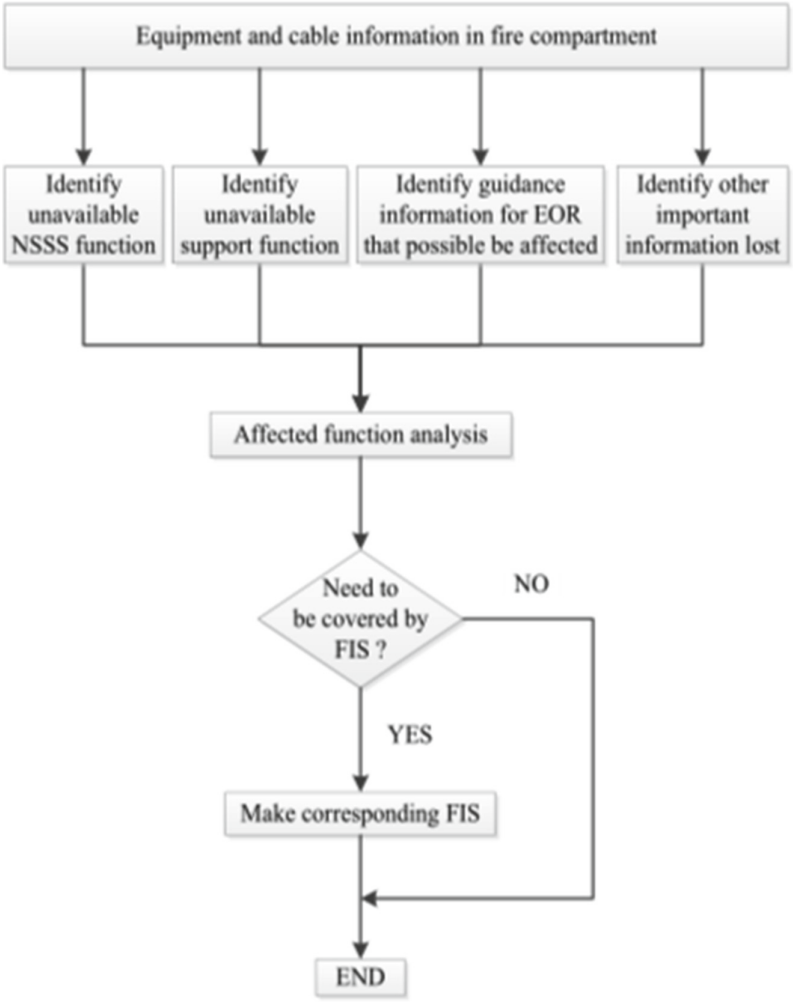

Fig. 1. Process of fire consequence analysis.

done, the signal is the affected information. For the signals with all signals lost from measuring instruments, it is necessary to design alternative information to ensure the correct orientation of EOR.

Other important information. Signals or equipment information that do not belong to the above two types of information, but provide reference for operators in order to make them fully understand the detailed information of the unit. By collecting the equipment information in the fire zone and cable information (without fire protection), the corresponding equipment information is sorted out. If the information of the equipment composition participates in other important unit functions, the information should be included by other important information affecting the unit operation.

Through the influence analysis of the NSSS function, support function, guidance information necessary for EOR and other important information of the unit in the fire zone, the fire consequences of the fire zone can be summarized. Then, combined with the compilation criteria of the fire accident operation guidelines, the corresponding FIS is compiled. The specific fire consequence analysis steps are shown in Fig. 1.

4 Experience Feedback of Fire Consequence Analysis

According to the experience feedback of the second generation PWR nuclear power plant fire consequence analysis, fire protection can be appropriately adopted to avoid excessive FIS compilation.

According to the result of fire consequence analysis, this fire zone needs to be covered by FIS. However, if the specific cables are protected against fire, the preparation of FIS can be avoided, and the corresponding cables can be designed against fire. This is because FIS belongs to the file system of emergency operation, which increases the workload of operators and is not conducive to the convenience of unit operation. To reduce human error, the number and frequency of FIS documents should be reduced as much as possible. Therefore, this experience feedback is also applied to the equipment fire protection of the third generation nuclear power plants, and the results of fire consequence analysis are iterated with the equipment fire protection design in time.

5 Intelligent Exploration of Fire Consequence Analysis

There are many complicated nuclear power units, including more than 20,000 valves and hundreds of thousands of cables. It is difficult to respond quickly only by relying on the operator to analyze the fire consequences of fire-fighting equipment in fire zones when a fire accident occurs. With the advantage of computer intelligence, the consequences of initial fire accidents can be quickly and automatically diagnosed, and the fire consequences in fire zones can be monitored and diagnosed, so that operators can quickly know the state of the unit under fire accidents, provide decision-making basis for operators to stabilize the operation of the unit, and help operators to intervene in time to bring the unit to a safe state.

Nuclear power plant fire accident consequence monitoring system is an intelligent system for rapid diagnosis of fire accident consequences. By combing the NSSS function of the unit, the database of unit support function, the guidance information necessary

for EOR implementation and other important information, the system establishes the database of implementing fire accident consequence diagnosis. Sort out the information of fire-fighting zone equipment and establish the information database of fire-fighting zone equipment. When the fire in the fire zone is confirmed, the equipment information of the fire zone will be automatically imported into the fire consequence diagnosis module, and the information in the fire accident consequence diagnosis database will be automatically compared to diagnose the fire consequence in the zone. And displayed through the man-machine interaction screen of the fire consequence display module.

6 Conclusions

In this paper, the application of the new fire consequence analysis method in the fire protection design of the third generation nuclear power plant is studied, including the fire accident design standard of Hua-long one unit, the fire consequence analysis content, the fire consequence analysis process and the experience feedback in engineering practice, etc., and the exploration of intelligent fire consequence analysis in nuclear power plants is briefly introduced.

The practical application of the new fire consequence analysis method in Hua-long one unit provides a basis for the fire protection design of related equipment and the compilation of FIS, and also provides a model for the fire consequence analysis of the following three generations of nuclear power plants. At the same time, the exploration of intelligent direction also points out the direction for the intelligent research of fire consequence analysis of nuclear power units.

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