A framework for nuclear power plant emergency response system

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Abstract The purpose of this study is to establish an intelligent expert system for nuclear power plant emergency response. A new framework of environmental risk management methodology by the concept of pattern recognition was introduced in this paper. A knowledge-based decision support system for emergency response and risk management of nuclear power plant was also discussed. The mathematical pattern relationship of accidental release effects on neighboring area and the corresponding response measures were presented in this paper. With this decision system, the decision maker can specify the procedure and minimize their human error in the decision process. The improvement of risk response and the quality of management system could be upgraded by this system. Besides, the methodology can also be served as a basis for the future development of environmental risk response system design.

Key words Expert system, Emergency response, Risk management, Nuclear power plant.

1 Introduction

Owing to the concern of global climate change, the nuclear power has been paid more attention recently. However, lessons from Chernobyl disaster made us be more careful about the emergency response of nuclear power plant[1]. Since Taiwan is a very small island with highest population density, we need to ponder in designing the emergency response system.

Nuclear power plants are very similar to the traditional power plant. They rely on the turbine operating to generate the power. Different types of power plant use different energy to start the turbine. For example, the hydropower plant uses the flowing water to push the turbine and generate the electricity. A nuclear power plant or a thermal power plant uses high temperature and high pressure steam to move the turbine.

The high temperature is made by different fuels such as coal, oil, natural gas, and uranium. In the process of steam generation, there are gaseous exhausts released from the plants to the environment. If these are controlled under a well designed control system, it will be very secure. However, if the release is with dangerous materials, it will be very dangerous to the community.

The decision support system is useful for managing the emergency response system. Many researchers have made efforts in the emergency response decision support system[8,10,11]. Some have applied this idea in the nuclear power plant emergency management[8,10,11]. About the study in Taiwan, Chang *et al*.[2] studied a decision support system for emergency response system and risk management of nuclear power plant in Taiwan. Chen *et al*.[6,7] studied the environmental risk management by multi-variable analysis of pattern structure, and submitted an idea about the expert system for managing emergency response of environmental disaster. In these researches, however, the response measures were not designed with a systematic thinking. This paper tries to combine the concept of management pattern with the space-time relationship of emergency response system. A framework of the system including the concept and equation was described in detail in this paper.

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2 Concept of disaster management

The design of environmental disaster system includes the five steps, which are described as follows.

(1) Identify concept to represent knowledge;

The major risk to be concerned is the transport by radioactive aerosol. Transport phenomenon is directly related to the meteorological parameter such as wind speed and direction.

(2) Find concept to represent knowledge;

Risk can be used as the concept to represent the degree of nuclear power plant disaster. The dose is the quantity of an active agent(substance or radiation) taken in or absorbed at any one time, and is a function of time and concentration. For example, the iodine may release into the atmosphere and influence the air concentration and become the thyroid dose and effective dose. The aerosols may enter into the atmosphere and also become the thyroid dose and effective dose the noble gas goes into the cloud shine and become the effective dose.

(3) Design structure to organize knowledge;

The natural phenomenon can be represented by a mathematical vector. The risk of a nuclear power plant is of a space-time event, and generally the natural environment is of a space-time information phenomenon, too. They can be described by the same equation. The space geographical information can be represented by Eq.(1).

$$I = \sum_{i=1}^{m}\left[\sum_{j=1}^{n}\begin{bmatrix} S_{ij}\left(T_{ij}\right) \\ A_{ij}\left(T_{ij}\right) \\ T_{ij} \end{bmatrix}\right] \tag{1}$$

$$T_{ij}(t_{\mathrm{b}}, t_{\mathrm{e}})_{ij}$$

where I is the collection of space geographical information; i is the individual vector for the i^{th} item, j is the state of this item; $S_{ij}(T_{ij})$ and $A_{ij}(T_{ij})$ represent the characteristics of this item in time t_{b} to t_{e}. The inferences of the above equation are the following:

Inference 1 If i is constant, Eq.(1) represents the time series data of the same characteristic.

Inference 2 If j is constant, Eq.(1) represents the characteristic distribution in the same time.

(4) Formulate rules to embody knowledge;

The logical formulation was used to generate a rule to compare the risk value of the event and take the necessary action. When the limit value was defined, then the action will entry according to the results value either "true" or "false". If the result is too complicated, then the "decision tree" can be applied[9,12].

(5) Validate rules that organize knowledge.

3 Knowledge bank analysis and data base design

The knowledge bank of nuclear power plant is shown as Fig.1.

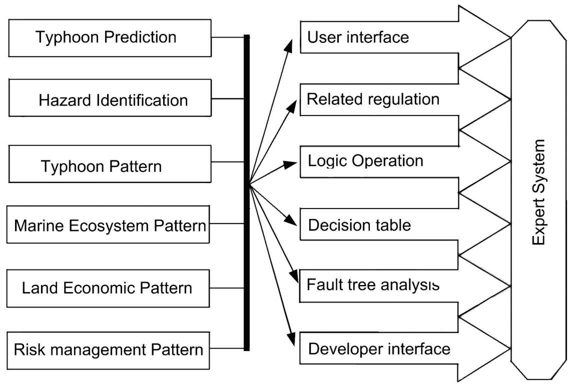

Fig.1 Intelligent knowledge-based expert system.

The knowledge bank contains the model bank, pattern bank, and regulation bank. In designing the expert system of nuclear power plant emergency response management, we have to use the necessary model to choose the appropriate response measure. There are three major types of model, i.e. meteorological model, diffusion model, and economic model. The meteorological model for nuclear power plant includes the Gaussian model, trajectory model, and grid model. The economic model includes the housing damage model, agriculture loss model, indirect economic loss model, and post disaster reconstruction model.

The data base of nuclear power plant emergency response system include the meteorological data, spatial data, attribute data (such as population, terrain etc.), source data, etc.

There are three nuclear power plants operating in Taiwan and one under construction. Table 1 is the description of the four nuclear power plants in Taiwan. Fig.2 is the location of them. The framework about the risk managing of nuclear power plant is described in Section 4.

Table 1 Description of the four nuclear power plants in Taiwan.

Plant	No.1	No.2	No.3	No.4
Location	Shihmen Township, Taipei County	Wanli Township, Taipei County	Hengchun, Pingtung County	Gongliao Township, Taipei County
Commercial operation date	#1, December 1978 #2, July 1979	#1, December 1981 #2, March 1986	#1, July 1984 #2, May 1985	
Installed capacity/ MW	636	985	951	1,375
Reactor type	Light-water reactor (Boiling Water)	Light-water reactor (Boiling Water)	Light-water reactor (PWR)	Light-water reactor (PWR)

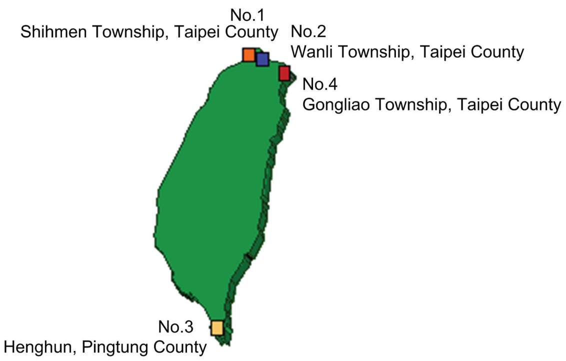

Fig.2 Location of nuclear power plant in Taiwan.

4 Emergency response system

4.1 Inference mechanism

The emergency response system uses the IF/ THEN inference mechanism. IF represents the obtained information and THEN represents the action. Table 2 is an example of the IF/THEN operator.

4.2 Risk management pattern

Different kinds of pattern model for nuclear power plant disaster management are listed in Table 3.

Table 2 IF/THEN operator for nuclear power plant.

IF	Logical operator	Example	THEN
>	Greater than	Radio-nuclide transport from the fuel rods into the gap	Action(1)
<	Less than	Radio-nuclide transport from the fuel cladding into the coolant	Action(2)
≥	Greater than or equal to	Loss of coolant accident transport from the coolant to the containment	Action(3)
≤	Less than or equal to	Containment design basis leakage and failed-close isolation valves	Action(4)
=	Equal to	Routine effluent releases from condenser	Action(5)
and	AND	Steam line safety valves and PORV release to the atmosphere	Action(6)
or	OR	Letdown line and ECCS regulation from the RB sump into the auxiliary build	Action(7)
!	NOT	Auxiliary building vent	Action(8)

Table 3 Four types of pattern model in nuclear power plant disaster management system.

Disaster pattern	Diffusion pattern	Economic pattern	Management pattern
Strength	Gaussian diffusion model	Housing damage	Reinsurance
Location	Trajectory model	Personal injury and death	Compensation
Frequency	Grid model	Agriculture	Super fund
Time	Pollutant path prediction	Roads and bridge damage	Major disaster securities
Duration	Cloud model	Indirect economic loss	Market
Terrain	Vertical wind distribution	Post disaster Reconstruction	Social public disclosure
Wind field	Remote sensing generated	Costs	Education and training
Temperature	Meteorological parameter		Emergency Response
Variation			Human resource

4.3 More discussion about the regulation and action data base

The risk management should follow the regulations; therefore, a regulation bank for the response measure is necessary for the management system. Following the decision results from the expert system, we have to take action to prevent the economic loss; these actions could be represents by the following models:

$$\begin{aligned} M &= (\text{Action}_1, \text{Action}_2, ..., \text{Action}_n) \\ &= (m_1, m_2 ......m_n) \\ &= \sum_{i=1}^{n} m_i \end{aligned} \quad (2)$$

where M is the collection of emergency response measure; Action i is the individual vector for the i^{th} measure. Each action is represented by a symbol m; and there are m measures in the action domain. If the risk management system is good enough, there should have enough measures to solve problems encountered in a typhoon disaster. Therefore, we have the following inferences:

Inference 3 If i is constant, then for each $S_{ij}(T_{ij})$ and $A_{ij}(T_{ij})$, there exists a measure m_i in the emergency response measures domain.

Inference 4 If j is constant, then for each $S_{ij}(T_{ij})$ and $A_{ij}(T_{ij})$, there exists a measure m_i in the emergency response measures domain.

5 Conclusion and Suggestion

The expert system for nuclear power plant was established in this study. It utilizes the information technology to prevent the possible emergency condition of a nuclear power plant. The system was designed with the knowledge-based decision support system for emergency response and risk management. The system can be used as the emergency preparedness or emergency response guideline. Since it is only a framework in the present stage, more efforts can be made with regard to this result. The wind field and social data base is necessary for the future development of this system.

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