Counter Action Procedure Generation in an Emergency Situation of Nuclear Power Plants

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Abstract. Lessons learned from the Fukushima Daiichi accident revealed various weak points in the design and operation of nuclear power plants at the time although there were many resilient activities made by the plant staff under difficult work environment. In order to reinforce the measures to make nuclear power plants more resilient, improvement of hardware and improvement of education and training of nuclear personnel are considered. In addition, considering the advancement of computer technology and artificial intelligence, it is a promising way to develop software tools to support the activities of plant staff. This paper focuses on the software tools to support the operations by human operators and introduces a concept of an intelligent operator support system that is called as co-operator. This paper also describes a counter operation generation technique the authors are studying as a core component of the co-operator.

1. Introduction
Lessons learned from the Fukushima Daiichi accident revealed various weak points in the design and operation of nuclear power plants at the time [1] although there were many resilient activities made by the plant staff under difficult work environment. The factors that obstructed suitable counter activities can be summarized as weak power source and service systems against tsunami, excessive dependence on remote control, insufficient communication means for information sharing, weakness of lightning and monitoring outside the building, and insufficient tools to remove a heap of rubbles. These mean that the measures necessary for the fourth layer in the concept of defence in depth [2] were insufficient.

In order to reinforce the measures in the fourth layer to make nuclear power plants more resilient, improvement of hardware and improvement of education and training of nuclear personnel are considered. In addition, considering the advancement of computer technology and artificial intelligence, it is a promising way to develop software tools to support the activities of plant staff.

This paper focuses on the software tools to support the operations by human operators and introduces a concept of an intelligent operator support system that is called as co-operator [3, 4]. This paper also describes a counter operation generation technique the authors are studying as a core component of the co-operator.
2. Concept of co-operator

2.1. Roles of human operators
One of the expected roles of human operators in plant operation is to carry out situation awareness [5]. The situation awareness is an abstract conception that includes detecting an anomaly, identifying the anomaly cause, and predicting future plant behaviour. In addition, human operators are asked to take suitable counter operations based on counter operation procedures in an abnormal plant situation.

The newly constructed nuclear power plants equip with a large screen to share important information among human operators and VDU (Visual Display Unit) based operation panels to give flexible ways of monitoring and operating a plant. In this new control room, some autonomous intelligent systems support human operators. In this style of plant operation, information sharing among human operators and autonomous intelligent systems becomes important.

2.2. Co-operator
Considering the technological advancement, especially, in computer technology, artificial intelligence, and robotics, the concepts of system configuration of a future operation support system will include remote operation support, co-operator, augmented sense, and online system maintenance [6].

The co-operator is a concept of intelligent system to support human operators as shown in Fig. 1 [3, 4]. It monitors plant condition through plant instrumentation system and interacts mutually with human operators. Its expected roles are a subordinate to accurately execute the tasks requested by human operators, a partner to share operation tasks, and an adviser to give useful knowledge and information.

![Co-operator diagram](image_url)

*Fig. 1 Co-operator*

The topics of developing a co-operator include monitoring plant condition by different viewpoints from those of human operators as well as the same viewpoints of them, moderate backup of the errors made by human operators, easy understandable explanation generation of processes and conditions of reasoning made by the co-operator, and understanding the intentions of human operators.

3. Counter operation procedure generation

3.1. Functional information
The authors are studying a technique to generate plausible counter operation procedures in an emergency plant situation as a core component of the co-operator [7, 8]. The technique utilizes a qualitative reasoning based on a functional model constructed in the framework of Multilevel Flow...
Modelling (MFM) [9, 10, 11], although quantitative information can be generated by a combination of numerical simulation package [12].

Functional information expresses the role and objective of a component. The features of a functional model are a) correlation of role and purpose with system behavior, b) implicit representation of causal relations, c) hierarchical modeling capability, d) involvement of linguistic representation, and so on.

We utilize MFM as a functional modeling framework. An MFM model expresses an engineering system from the standpoint of means and goals. The characteristic feature of the MFM is to use a set of primitive function concepts to represent goals, functions, and their relations. An MFM model expresses the functional information of a system in a graphical way using objective and functional nodes and relation arcs.

3.2. Technique to generate counter operation procedures

In the counter operation procedure generation, the influence of an operation on plant future behavior is inferred along the causality relations implicitly expressed in an MFM model. For the inference, inference propagation rules [7, 11, 13] are derived in advance for each pattern of relation among function nodes and objective nodes. An algorithm to generate plausible counter operation procedures is developed.

The applicability of the algorithm is examined in several small break LOCA (Loss-Of-Coolant Accident) cases of a PWR (Pressurized Water Reactor) plant [7]. Three severe accidental situations of a PWR plant are considered. All of them are LOCA (Loss Of Coolant Accident) cases after the detection of partial core damage with the conditions such that (A) the ECCS (Emergency Core Cooling System) and main steam relief valve fail to initiate, (B) the residual heat removal system does not work, and (C) internal spray system fails to initiate. As shown in Table 1, the developed system successfully generates counter operation procedures including the procedures called AM (Accident Management) prepared for Japanese PWR plants.

| Case | Generated procedure | Accident management |
|------|---------------------|---------------------|
| A    | 1. Open MSIV (Main Steam Isolation Valve) | 1. Open MSIV |
|      | 2. Open TBV (Turbine Bypass Valve) | 2. Open TBV |
| a    | 1. Open pressurizer relief valve | |
| b    | 1. Open pressurizer relief valve | |
| B    | 1. Open tie-line valve | 1. Open tie-line valve |
|      | 2. Open residual heat removal valve | 2. Open residual heat removal valve |
| b    | 1. Open pressurizer relief valve | |
| c    | 1. Open main steam relief valve | |
| d    | 1. Open main steam relief valve | |
| C    | 1. Open pressurizer relief valve | |
|      | 1. Open main steam relief valve | |
| a    | 1. Open MSIV | |
| b    | 1. Open TBV | |
| c    | 1. Open residual heat removal valve | |
| d    | 1. Open residual heat removal valve | |
| e    | 1. Open fire protection system valve | 1. Open fire protection system valve |
|      | 2. Open containment spray valve | 2. Open containment spray valve |

Table 1. Generated operation procedures
4. Conclusions

This paper deals with software tools to support the operations by human operators to make nuclear power plant more resilient and introduces a concept of an intelligent operator support system that is called as co-operator. This paper also describes the outline of a counter operation generation technique as a core component of the co-operator.

Although there are many technological developments are necessary to implement an integrated intelligent system like co-operator, the author hopes that this kind of software tools will improve the safety of nuclear power plants to reinforce the fourth layer of defence in depth.

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