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Knowledge Base Prediction System to Identify Optimized Paths for THOMAS

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Abstract

The online monitoring and advisory system is needed for the operator to cope with transients to prevent the core damage, to mitigate and ultimately terminate the progression of core damage once it has begun, to maintain containment as long as practically possible, and to minimize off-site radiation releases to the environment and the public. The plant operational data such as abnormal symptoms or accidents are required for the operators to ensure safety of nuclear plants. The monitoring and advisory system can serve to detect and identify the abnormal status of the plant early in the transient. THOMAS (Thermal Hydraulics Online Monitoring Advisory System) is being developed for this very purpose. The main features include three-dimensional (3D) monitoring interfaces in the virtual space and the knowledge base (KB) prediction algorithm. The 3D display of THOMAS provides the operators with highly visual ubiquitous man-machine interface to comprehend plant control system. In addition, in the KB algorithm of THOMAS, accident management can be effectuated using the existing and alternative resources, systems, and actions to prevent or mitigate the accident. The KB system is developed for training the main control room staff and technical support group. The system consists of the phenomenological KB, accident sequence KB, and accident management procedures with strategy control diagrams and information needs. The system aims to contribute to training the operators by providing with

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phenomenological knowledge on the accident at hand, by understanding the plant vulnerabilities, by evaluating the associated risk, and by solving problems under high stress. The THOMAS operator support system with the advisory and monitoring function is validated against the plant operation and control system such as the main control room data.

1. Introduction

The plant operational data such as abnormal symptoms or accidents are required for the operators to ensure safety of the nuclear plants. The monitoring and advisory system can serve to detect and identify the abnormal status of the plant early in the transient. Immediate monitoring of plant systems and equipment by the operators will enable early detection and recognition of failure and accident in the nuclear plant system.[1] As presented in Fig. 1, THOMAS (Thermal Hydraulics Online Monitoring Advisory System) is being developed for this very purpose via the visual representation of the plant status.

Fig. 1. THOMAS representation of the primary system

The main features include the fully three-dimensional (3D) monitoring interfaces in the virtual space and the knowledge base (KB) prediction algorithm. The 3D display of

THOMAS provides the operators with user-friendly ubiquitous network to help comprehend the plant control system.

The new concept of process algorithm was applied in THOMAS to identify the plant state and give early warning to the operator. Generally, accident management can be defined as the use of existing and alternative resources, systems, and actions to prevent or mitigate core melting. This will extend the defense-in-depth philosophy to severe accident. The accident management includes the measures to prevent core damage, to terminate the progress of core damage if it begins and retain the core within the reactor vessel, to maintain the containment integrity as long as possible, and to minimize the consequences of offsite release.[2] A training program needs to be developed to enable the operators to use these measures successfully. The training program is basically required to cover several topics including the progression of severe accidents, severe accident phenomena, the IPE (Individual Plant Examination) findings of a reference plant, and the accident management procedures.[3] A KB system, developed for those purposes, is introduced in this paper.

The initiation point for KB and scopes of the emergency operating procedures and severe accident management strategy are illustrated in Fig. 2. The KB system, written in html, may provide awareness training to the operators whose work may create a significant impact upon safety of the plant during an accident. It may be basically used for fundamental training in the severe accident assessment and response strategies, instrument degradation under severe accident condition, and alternative instrumentation to verify instrument reading necessary for the implementation of severe accident strategies.

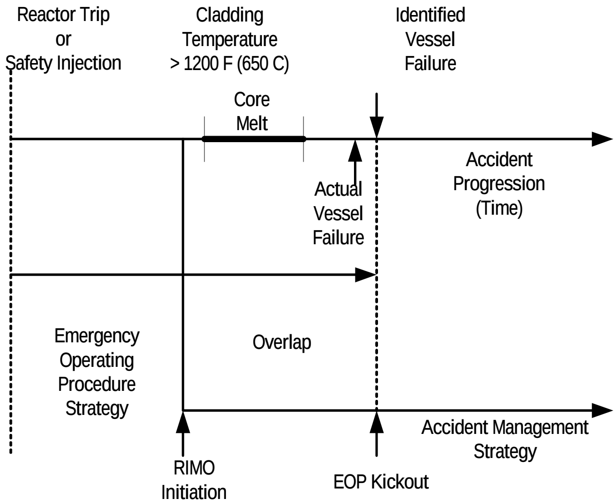

Fig. 2. Initiation timing for use of RIMO

The KB is basically developed to help the control room operators and staff to answer questions such as the following.

What are the possible accident sequences given the current conditions? What is the expected physical accident status after some evident symptoms? What are the minimum equipment requirements in order for accident management strategies or procedure to be effective? What are the adverse consequences if some of actions are initiated prematurely?

2. Overall Features

Training for accident management is especially critical in order to overcome the degradation of performance that can occur during stressful situation, to reduce the potential for human error during transition from the emergency operating procedures to accident management procedures, and to promote more effective communication between the control room staff and technical support group. A well designed training program will ensure that all personnel involved in accident management have a common understanding of severe accident phenomena such as the steam explosion, hydrogen burn, direct containment heating, etc., the conceptual basis of the accident management procedures, and the roles and responsibilities of the personnel during execution.

RIMO (Risk Meter for Operators), as presented in Fig. 3, comprises the phenomenological KB, accident sequence KB, and accident management procedures and information needs.

The system was developed for use as a part of this training program focused on achieving a fundamental understanding of “what’s happening?” during an accident. The KB is a collection of facts regarding accidents and rules for decision making associated with problem solving. Detailed functions of this system include definition of the accident management, accident sequences, probable accident phenomena with respect to each progression step, accident management strategies, accident management procedures, and frequenting human errors. These contents include on how an accident progresses as well as how the accident management procedures should be presented to be easily understood and legible, especially under the stressful conditions expected during the accident.

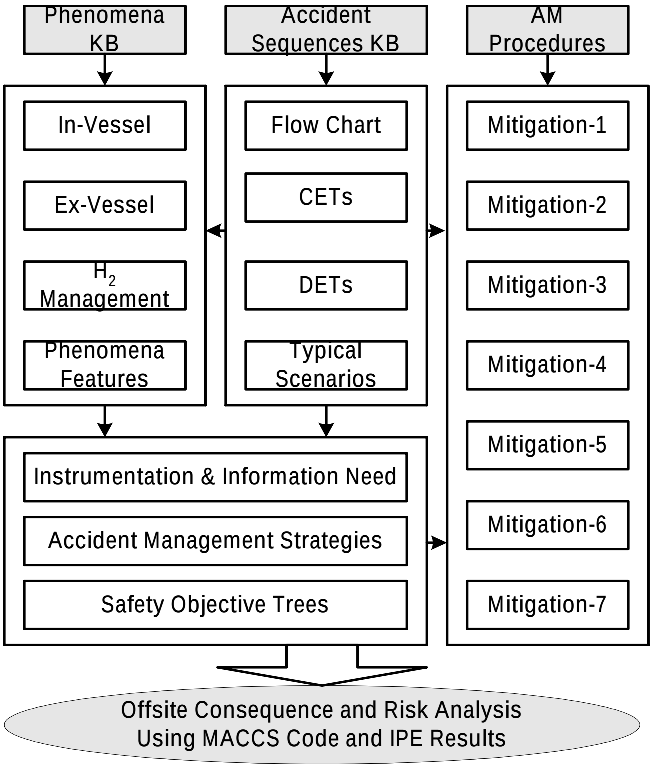

Fig. 3. Structure of RIMO

3. System Description

The UCN 3&4 pressurized water reactor plants are used as the reference plant.[4] The plant configurations and accident scenarios, accident phenomena KB, and information and instrumentation KB were incorporated in RIMO. The accident phenomena KB element in the RIMO structure includes core melt progression, in-vessel steam explosion, ex-vessel steam explosion, hydrogen burn, direct containment heating, missiles, and molten core concrete interaction.

Fig. 4 represents the screen displaying the most pivotal elements in the accident assessment, and the main menu for training the operators and staff. Each element comprises both schematic diagrams and explanations on accident phenomena and sequence.

The same structures for the other elements of the accident sequence, accident management procedures, and information and instrument were implemented in RIMO. The system on the whole consists of five modules with the following functions.

Fig. 4. Menu for RIMO

1. Phenomena

The phenomena contains the core melt progression, in-vessel steam explosion, ex-vessel steam explosion, hydrogen burns, direct containment heating, missiles, molten core concrete interaction, etc. For the phenomena of steam explosions, explanations with important governing equations associated with heat transfer theory (conduction, convection, and radiation) are given in the left column of each display. Energetic steam explosions inside the reactor vessel due to core relocation pose two different kinds of threats to the vessel integrity. The a-mode failure is a mechanism in which a steam explosion in the reactor lower plenum accelerates a coolant slug towards the vessel head, which breaks off, becomes a missile and penetrates the containment roof. When the molten material discharges from the reactor vessel, the step-by-step progression diagrams coming into contact with water in the reactor cavity is also incorporated in this system. In the same manner, other important phenomena are depicted with supporting diagrams.

2. Accident Sequences

An accident progression flowchart is modeled with respect to time, temperature, sequence event, and likely outcomes. This module offers the trainee overall accident progression pictures. For more details, the containment event trees (CETs), which are the precalculated IPE results, are also incorporated in the system.[5] The decomposed event trees (DETs) are linked to the nine top event headings of CETs, as demonstrated in Fig. 5. They contribute to predicting the possible accident sequences for operators and staff during accidents.

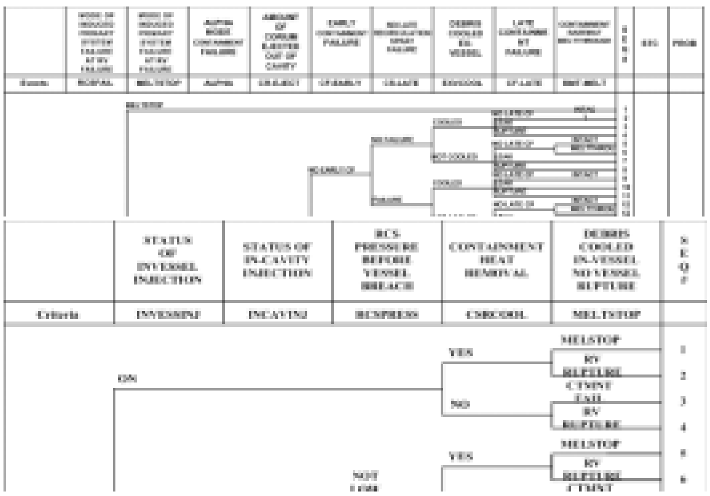

Fig. 5. Accident sequence of CETs/DETs in RIMO

3. Accident Management

The accident management procedures consist of emergency guidance, strategy control diagram, and mitigation guidance. The emergency guidance is a set of actions before or after the technical support center actuation. The mitigation guidance is necessary for the control of fission product release, containment integrity, reactor vessel integrity and exit guidance for the technical support center staff.[6]

4. Information and Instruments

Accident management procedures require a wide spectrum of plant information to make decision, by which the accident management procedures be used at the current conditions.[7] Necessary information is collected via various instrumentations. The safety objective trees and several computational aids are also incorporated in the KB system to provide with necessary information.[8]

5. Offsite Consequence Analysis

The accident consequence analysis is defined to assess effects on health and environment caused by radioisotopes released from the plants. The MACCS system is incorporated in this system in three modules: ATMOS, EARLY and CHRONC.[9] The ATMOS module treats the atmospheric dispersion and transport of material and its deposition onto the ground. The EARLY module includes direct exposure pathways, dosimetry, mitigative actions and health effects during the emergency phase. The CHRONC module evaluates the direct and indirect exposure pathways, dosimetry, mitigative actions, and health effects during the period that follows the emergency phase: the intermediate and long-term phases. CHRONC also includes the economic costs associated with the mitigative actions during the emergency, intermediate, and long-term phases. As portrayed in Fig. 6, the offsite consequence analysis module as well as the IPE module is loaded to assess the radiation risk.

Fig. 6. Realization of MACCS system

4. Conclusion

Accurate prediction of accident progression as practicably possible is critical in overcoming degradation of performance that result in a stressful situation. The KB system in THOMAS is developed for identifying the probable event sequences as well as training control room staff and the technical support group. The KB system consists of the phenomenological KB, the accident sequence KB, accident management procedures, information needs and consequence analysis using MACCS. This system shall be useful in predicting the accident sequence through the containment event trees and accident management procedures by gaining phenomenological knowledge involving the accident, understanding plant vulnerabilities, evaluating risk and solving problems under high stress.

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