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Development of an Operator Aid System For The Nuclear Plant Severe Accident Training and Management

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Abstract: Recently KAERI has developed the severe accident management guidance to establish Korea standard severe accident management system. On the other hand the PC-based severe accident training simulator SATS has been developed, and the MELCOR code is used as the simulation engine. SATS graphically displays and simulates the severe accidents with interactive user commands. The control capability of SATS could make a severe accident training course more interesting and effective. In this paper the development and functions of the electrical hypertext guidance module HyperKAMG and the SATS-HyperKAMG linkage system for the severe accident management are described.

Key words: nuclear power plant, severe accident, simulator, realtime control, SPDS

1. Introduction

For the appropriate execution of severe accident strategy, more information for decision-making is required because of uncertainties included in severe accidents of nuclear power plants. In the case that a beyond design basis accident occurs, the whole plant safety ought to depend on operators behaviors completely. If the operators do not recover the plant, the plant may be severely challenged and radioactivity may be released from the damaged fuels to containment. However due to the uncertainties in severe accident phenomena and scenarios, only the recovery guidelines are developed instead of the detailed recovery procedures. Since plant behaviors under severe accidents could not be expected correctly, various severe accident knowledge base and PSA technologies together with the continuous plant monitoring become very important for optimal decision-making.[1]

In Korea, the severe accident management guidelines (KAMG) were developed recently,[2] and it is supposed to be a skeleton of the architecture of severe accident management as in foreign country. The development of KAMG leads to the development of related training system for severe accidents. HyperKAMG, the severe accident guidance module, has full contents of KAMG in the hypertext format. Whenever alarms in safety parameter display system (SPDS) of SATS appears, operators in MCR and technical support center (TSC) staffs can follow the HyperKAMG severe accident mitigation procedures. According to KAMG, the HyperKAMG module consists of several parts, which are emergency guidance, strategy control diagram, mitigation guidance, exit guidance, technical backgrounds, equipment checking tables and calculation aids.

SATS is the training graphic simulator, developed to provide a multi-purpose tool for severe accident analyses and training.[3-6] It aimed to have two main functions: one is to provide graphic displays to represent severe accident phenomena and the other is to process interactive user inputs. SATS simulates nuclear plant behavior using MELCOR code as its engine, and provides graphical displays of plant behaviors. Moreover SATS has the real-time control function so that every important valves and pumps are controllable by interactive mouse operations without changing scenario inputs.

2. Development of the Severe Accident Guidance Module

2.1. The Severe Accident Management Guidance

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In 1988, the severe accident management guidelines for the Korean standard nuclear power plants (KAMG) were developed at KAERI. These guidelines were designed to be applied to the severe accident cases, where core is melted down so that emergency operation procedures are not applicable. KAMG consists of several parts, which are emergency guidance, strategy control diagram, mitigation guidance, exit guidance, technical backgrounds, equipment checking tables and calculation aid.

There are two different guidelines which are the guidelines of the main control room (MCR) and the guidelines of the technical support center. (TSC) The core guidelines of KAMG are the seven severe accident mitigation strategies of TSC, and each strategy has its own calculation aids. The seven mitigation strategies in KAMG are

- MG-01: Supply feed water into steam generator (SG)
- MG-02: Depressurize reactor coolant system (RCS)
- MG-03: Inject into RCS
- MG-04: Inject into containment
- MG-05: Control fission product release
- MG-06: Control containment conditions
- MG-07: Control hydrogen concentration in containment

KAMG guidelines have all information related to strategy execution. The starting point of the mitigation guidance is the general description of selected strategy which includes five steps of available equipment check, decision of strategy, decision of execution methods, strategy execution and strategy exit

The order of precedence of each mitigation strategy is determined by the strategy control diagram as shown in Figure 1. In the strategy control diagram, all severe accident safety parameters which should be monitored during the accident, are described with their set points. TSC should monitor the plant status periodically via strategy control diagram until the plant becomes stable to be controllable by MCR operators. Using the strategy control diagram, TSC diagnosis the plant status, and makes decision which strategy should be taken precedence.

The exit guidance is performed when strategy control diagram regards the plant is stable enough to be controllable. After the end of severe accidents, several plant systems and structures are apt to be contaminated by radioactivity. Therefore very careful treatments are required in the recovery. In the exit guidance, several action items to give TSC the important information for the execution of recovery after severe accidents are

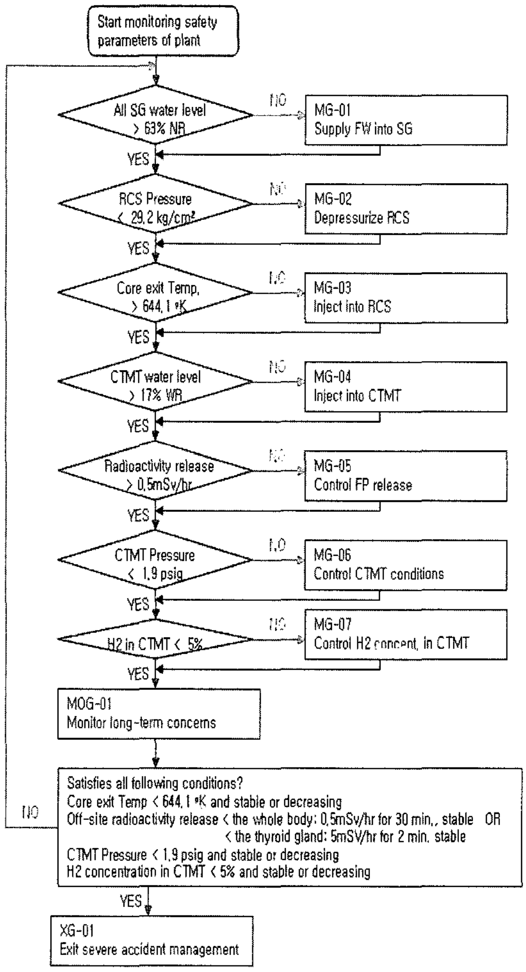

Fig. 1. Strategy Control Diagram of KAMG.

included.

The calculation tables are developed to help diagnosing plant status or to help decision-making process at TSC. These tables are especially useful when safety parameter information from instruments is unavailable or unbelievable.

Whenever a nuclear plant accident is not mitigated in the early phase and developed to become a severe accident beyond the scope of emergency operation procedures, MCR begins to follow the steps of the emergency guidance first and it is required to set up TSC simultaneously. After TSC sets up, TSC has all authorities and responsibilities in making decision such as mitigation strategy selection and execution.

2.2. The Severe Accident Management Module

HyperKAMG is the basic module of the severe accident training and management system. It has full contents of severe accident management guidelines of Korean standard nuclear power plants, so that all emergency

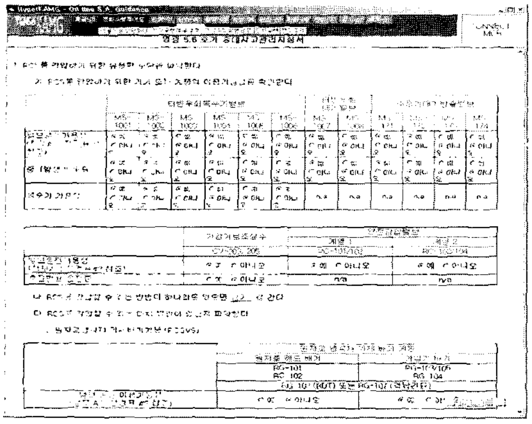

Fig. 2. The Appearance of HyperKAMG Module (Equipment Check List)

guidance, strategy control diagram, mitigation guidance, exit guidance, technical backgrounds, equipment checking tables and calculation aids are electrically computerized and included in HyperKAMG. Each mitigation strategy in the guidance goes through the process of checking available equipment, deciding strategy, deciding execution methods, executing strategy and exiting strategy. For the comprehensive aids in decision-making, HyperKAMG shows the current strategy execution step position in the whole process automatically. HyperKAMG will summarize the result of users decision for a severe accident as follows:

- selected equipment
- selected injection path if any
- selected depressurization method if any
- restrictions
- special parameters to be monitored
- etc

The summary will be sent to SATS via SPDS using "Connect MCR" button at the top right of HyperKAMG.

3. Severe Accident Training Simulator

Currently there are various kinds of severe accident analyses codes, and several severe accident management systems had been developed based on the analyses codes.[7-8] The severe accident training simulator was developed in step with the development of the severe accident management guidance (KAMG) in Korea. When utilities in Korea begin to use KAMG, plant operators should complete the severe accident training course. The development of the training simulator was required for the successful training.

SATS is a PC-based training graphic simulator, developed to provide a multi-purpose tool for severe accident analyses and training. It aimed to have two main functions: one is to provide graphic displays to represent severe accident phenomena and the other is to process interactive user inputs. SATS simulates nuclear plant behavior using MELCOR code as its engine, and provides graphical displays of plant behaviors. Using MELCOR code, it is possible to simulate the core and containment behaviors according to accident times. Moreover SATS has the real-time control function so that every important valves and pumps are controllable by interactive mouse operations without changing scenario inputs. Equipped with these control capabilities, SATS becomes a so-called severe accident graphic simulator. figure 3 shows the running appearance of SATS.

The control function of SATS is performed as follows. When a SATS user turns on or off a valve or a pump in the graphic window, SATS will change the memory variables of MELCOR without stopping current calculation, according to the user activity. After all, MELCOR continues to complete its calculation using the changed values, so that the control function works without change of current inputs. In figure 4, the effects due to the shutdown depressurize system (SDS) valve operation in the total loss of feed water accident (TLOFW) scenario was displayed. The left graphs of figure 4 are the original TLOFW graphs showing RCS pressure and reactor vessel water level respectively. The right graphs are obtained after 90% opening of SDS valve, showing the SDS valve operation results by comparison with their left graphs. These graphs show the plant behavior when SDS valve was chosen for RCS depressurization.

SATS has prepared several controllable equipments according to KAMG which are ECCS Recirculation VV, Atmosphere Dump VV, LPSI PP, HPSI PP, SDS

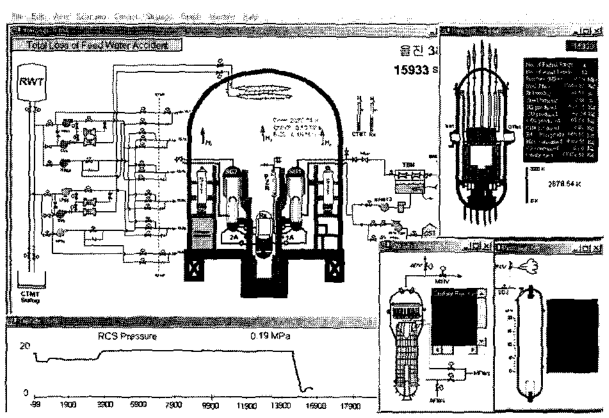

Fig. 3. SATS Running Appearance.

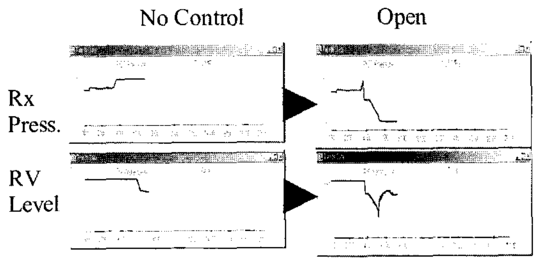

Fig. 4. Results of SDS Valve Control.

VV, AFW-PP (TD, MD), MFW-PP (TD, MD), Containment Spray PP, Containment Fan Cooler, H2 Ignitor, and Charging Pump. Each equipment has its own control panel displaying detailed information such as injection path status and warnings to prevent users mistake.

Another important feature of this simulator is that it provides graphical displays of reactor and other important plant systems. As seen in figure 2, the current status of reactor, pressurize and steam generator are displayed graphically, so that one can obtain deep insights about plant status easily. Moreover the cell-level display of the reactor core makes it possible for SATS to represent the core melting and relocation process graphically.

4. Development of SATSHyperKAMG Linkage System

4.1. Safety Parameter Display System (SPDS)

Due to the differences between emergency operation and severe accident operation, the critical functions monitoring system (CFMS), which is already running for the plant safety parameter monitoring at normal and abnormal operation, could not be used in severe accident situation. The differences are mainly caused by the difference of their safety objectives. The CFMS gives the plant information from the necessary safety function point of view, while in severe accident monitoring, the whole plant information should be reorganized to provide proper information for the prevention of the fission products release. For example, the current status of high pressure safety injection system (HPSI), low pressure safety injection system (LPSI), charging pump and containment spray pump should be recognized at a time for the successful execution of MG-02 (Inject into RCS). But by using CFMS, all above systems status could be recognized after complicated steps of changing windows. Thus the safety parameter display system (SPDS) of severe accident was reorganized to provide optimal information for each mitigation strategy execution.

As shown in figure 5, SPDS has seven alarms and twelve graphs for severe accident monitoring. The seven alarms are located at the top of SPDS window, indicating parameter status by blue, yellow and green colors. The seven alarms are based on seven mitigation strategies and their strategy control logic of KAMG. The seven alarms and its set points are as follows:

- SG water level, 63% NR
- RCS pressure, 2.86 MPA
- Core exit temperature, 644.1 K
- Containment water level, 8.91m Cavity Level
- Containment pressure, 0.114 MPA, 0.941 MPA
- H2 concentration in containment, 5%
- Radioactivity release, whole body:0.5mSv/hr, thyroid gland:5mSv/hr

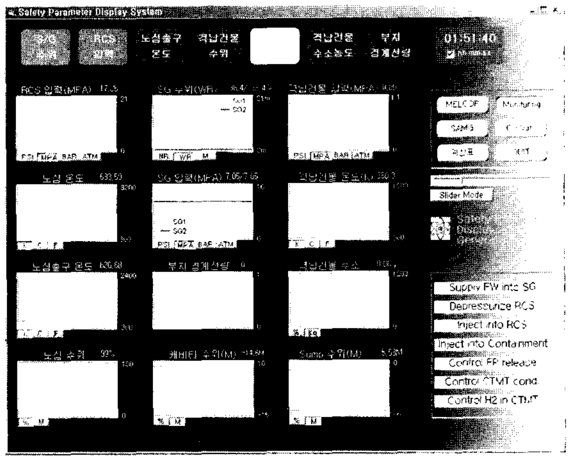

Fig. 5. Safety Parameter Display System.

Strictly speaking, SPDS should use the plant signal as input sources. But this prototype SPDS regards the SATS simulator as a real plant and it uses the simulated signals generated from MELCOR code instead of the plant signals. Since MELCOR cannot calculate the radioactivity release, the last alarm does not work, remained for further usage.

SPDS has twelve graph windows, displaying latest one hour trends of safety parameters, which are RCS temperature, SG water level, CTMT pressure, maximum core temperature, SG pressure, CTMT temperature, core exit temperature, radioactivity release, H2 concentration in CTMT, core water level, cavity water level and sump water level in order. This kind of graph design makes it possible to display both safety parameter current values and current trend which are very important information in severe accident decision-making.

Below the graph window there are several small buttons for unit selection. For example pressure unit can be any one of MPA, PSIA, BAR and ATM. The SG water level has different type of display option buttons for narrow range and wide range display. Finally SPDS provides full trend graph of selected parameters when any of the graph window is double clicked.

4.2. SATS-HyperKAMG Linkage via SPDS

The safety parameter display system (SPDS) in SATS plays a key role for SATS and HyperKAMG linkage. Originally SATS had internal SPDS system which can display safety parameters current values. For SATS-Hyper KAMG linkage, new SPDS which does not belong to SATS and HyperKAMG has been developed.

Figure 6 is the conceptual diagram of the SATS - HyperKAMG linkage system. As shown, SATS, MELCOR, SPDS and HyperKAMG are combined by the shared memory, running independently. Every calculation results are sent to the shared memory to be used by SATS and SPDS. Both SATS and SPDS use the same data generated by MELCOR for different purpose. SATS displays the plant behavior graphically and provides such user controllable equipments as pumps and valves. On the other hand, SPDS displays safety parameter information and generates the seven alarms according to KAMG logic. Once an alarm occurs, SPDS can invoke Hyper-KAMG system and wait monitoring the HyperKAMG decision-making process. The generated alarm signals go to HyperKAMG module and set of alarm signals are processed in HyperKAMG, according to the strategy control diagram to produce proper control command for SATS. The generated commands are sent to the display module of SATS via SPDS again, and the corresponding valves and pumps of SATS are controlled automatically.

4.3. Application Case: TLOFW Scenario

In order to prevent the radioactivity release, nuclear power plants generate steam for turbine driving at the steam generator instead of the reactor. TLOFW(Total loss of feed water) accident is the accident due to the loss of all feed water for steam generators cooling,

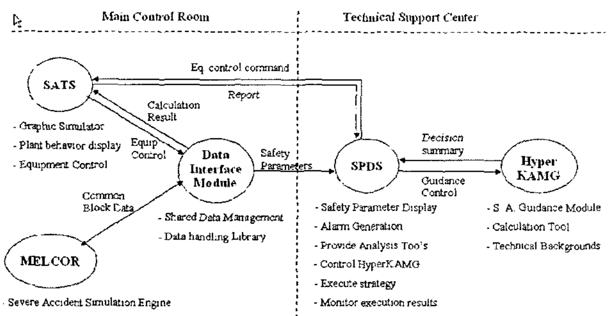

Fig. 6. Overall structure of SATS - HyperKAMG system.

which are main feed water(MFW) system and auxiliary feed water (AFW) system. TLOFW is often developed to be the core damaged accident, severe accident.

The important milestones of TLOFW without any operation are listed in the Table 1. The severe accident mitigation scenario for TLOFW is summarized at Table 2. Figure 7 presents the plant parameters at 11,000 seconds after TLOFW, showing that core temperature increases continuously and that steam generator water is dry out,

Table 1. TLOFW milestones (base case)

Time (s)	Important Phenomena
0	Reactor trip
3,546	Steam generator dryout
6,190	Start core uncovery
9,540	Core dryout
12,875	Core melting and relocation
13,259	Lower head penetration
13,597	SIT injection

Table 2. TLOFW milestones (after operation)

Time(s)	Important phenomena	Operation
0	Reactor trip	
3,000	Steam generator dryout	
	RCS pressure increase	
	CTMT pressure increase	
10,400	Core exit temp. > 644.1°K	
11,600	Execute MG-01	AFW on
	AFW restart	
11,900	Recover secondary inventory	SDS
	Execute MG-02	VV open

Assumptions:

After 2hr of TLOFW, AFW is repaired

Only SDS Valve is available for RCS depressurization

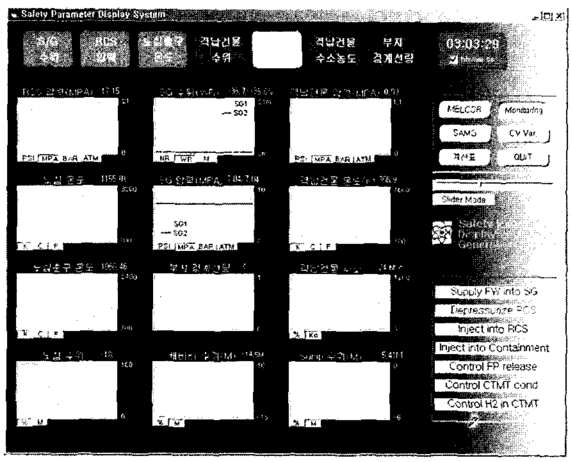

Fig. 7. TLOFW (11,000 sec)

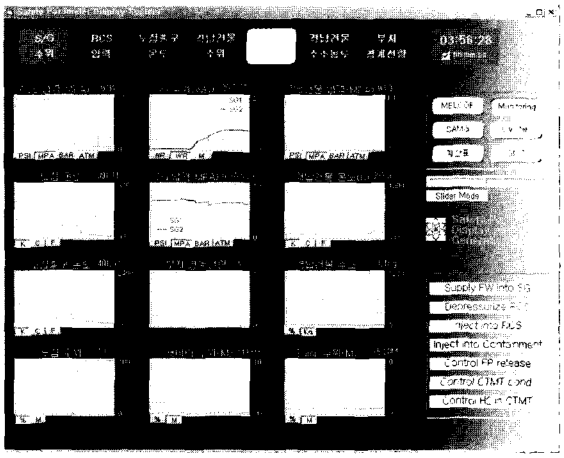

Fig. 8. TLOFW (14,100 sec).

which mean the accident is under development process to be a severe accident. Figure 8 presents the plant parameters showing the operation result which are listed in table 2. After the repair of SG aux feed water system, the secondary side water level is recovered, and primary side pressure is lowered by SDS valve opening operation. After all the low pressure safety injection system is started due to the low pressure, and the core status becomes stable.

5. Concluding Remarks

Because nuclear plant severe accidents are very rare, members in MCR and TSC are not familiar with their phenomena and mitigation procedures. Also it is not difficult to imagine their psychological pressure in an emergency. We have demonstrated SATS and Hyper-KAMG to plant operators, and have discussed about several problems in using our systems. The following requirements are asked for improvement: variety of severe accident data, easy and simple GUI, automatic communication between SATS and HyperKAMG, fast simulation speed, and integration of normal, abnormal and emergency plant monitoring and aids system.

In this paper, we have introduced the electric hypertext severe accident management guidance Hyper-KAMG, and the severe accident training simulator SATS. The KAMG logic and its strategy control diagram were described in detail. The idea of combining the KAMG logic and SATS control capabilities to mimic the severe accident management in a real plant was realized through the development of the SATS-HyperKAMG linkage system. The ultimate purpose for the severe accident management is to protect radiation release to environments. From this point of view, we expect that our SATS-HyperKAMG system to be an excellent tool for the severe accident management and training purpose.

Acknowledgement

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