DEVELOPMENT OF DESKTOP SEVERE ACCIDENT TRAINING SIMULATOR

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A severe accident training simulator that can simulate important severe accident phenomena and nuclear plant behaviors is developed. The simulator also provides several interactive control devices, which are helpful to assess results of a particular accident management behavior. A simple and direct dynamic linked library (DLL) data communication method is used for the development of the simulator. Using the DLL method, various control devices were implemented to provide an interactive control function during simulation. Finally, a training model is suggested for accident mitigation training and its performance is verified through application runs.

KEYWORDS : Nuclear Power Plant, Severe Accident, Accident Management, Training, Graphic Simulator

1. INTRODUCTION

In this paper, technical specifications in developing a severe accident training simulator, which can be used in severe accident management activities and power plant operator training, are discussed. The developed severe accident training simulator (SATS) is a desktop PC software system that provides an enhanced text based input/output (I/O) interface of MELCOR code by using graphic user interface (GUI) technologies. It shows several important severe accident phenomena and nuclear plant behaviors dynamically. During a simulation, the simulator continuously generates plant behavior and accident progression images by using thermal hydraulic parameters of the MELCOR code. In addition, the simulator also provides interactive control devices that even a non-expert user can operate to control accident progression. This function might be helpful to assess the effects of a particular accident management behavior on the accident progression.

Advances in graphic simulation using engineering code have been made mainly due to advances in computer technologies. Huge severe accident analysis codes, such as MELCOR, MAAP, ASTEC, SCDAP/RELAP5, which have previously been run on workstations, are currently distributed as PC versions.

Most earlier engineering codes utilized their own post-processing tools to show or print calculation results in forms of graphs. However, because of the limited graphic capability of the disk operating system (DOS) and FORTRAN programming language, these tools had poor graphic user interfaces. Real GUI systems for these engineering codes were developed after Microsoft provided Windows as a personal computer operation system (O/S). Using Window's advanced technologies, such as GUI and multi-processing architecture, several earlier GUI systems such as ATLAS[1] and MAAP-GRAPH[2] were developed. They can show the accident progression graphically during execution of the simulation engine, and provide several additional helpful tools for accident analyses.

GUI systems showing accident progression and handling user's interactive control commands were soon after developed. Among them are NPA[3-4], PCTRAN[5], VISA[6-7], SATS[8-9], and CAVIAR[10]. Due to the interactive control devices, they are referred to as graphic simulation systems.

In the next section, a simple and direct DLL data communication for the SATS is described. Even though the method uses the MELCOR code and SL Graphical Modeling System (SL-GMS), it can be applied to any other codes and other graphic tools. In addition, a simple method to display and control accidents without modifying any code input file are also described.

The main features of the SATS can be summarized as follows:

- SATS uses the MELCOR code as a simulator engine. It can display the sequence of the plant status by reading current MELCOR data from the DLL shared memory. Since it can use any MELCOR data, all of main features in the MELCOR design concepts can be added as simulator functions if necessary.

- By using an existing MELCOR input file, it can display a severe accident progression graphically. During the simulation, the user can manipulate valves and/or pumps interactively to simulate various accident progressions without modifying the input file.
- Plant behaviors at a severe accident are displayed via a commercial tool, SL-GMS. The driver module to assign dynamic properties of a SL-GMS graphic model is made using the SL-GMS graphic library. With the driver module and current MELCOR data, graphic animations of plant behaviors are established.
- SATS can be linked to an electronic hypertext severe accident management guidance (SAMG) module, HyperKAMG, for the purpose of severe accident training.

2. DEVELOPMENT TOOLS AND METHODOLOGY

The developed simulator SATS is a desktop software system that shows accident progressions graphically and provides several interactive control devices. In this section, the underlying concept and the technical methodologies utilizing in the development of SATS are described.

2.1 Construction of MELCOR Engine and DLL Shared Memory

In a multi-processing O/S such as Windows, any executable file becomes a unique process, having its own memory, file handles, and system resources. In Windows, each process has a 4 GB virtual memory, where the upper 2 GB becomes a shared memory accessible to any other processes. Normally, almost all of the processes are located in the lower 2 GB space, so as to be protected by other processes. However, DLL is a special type of executable, and resides in the upper 2 GB space, a shared memory space. In Fig. 1, there are three processes, MELCOR, SATS, and DLL. First, the DLL process initializes all necessary data, and then exports them to the MELCOR to be updated at each calculation cycle, while the same data are also exported to the SATS to be used in the accident status display and modification of control parameters for interactive equipment control.

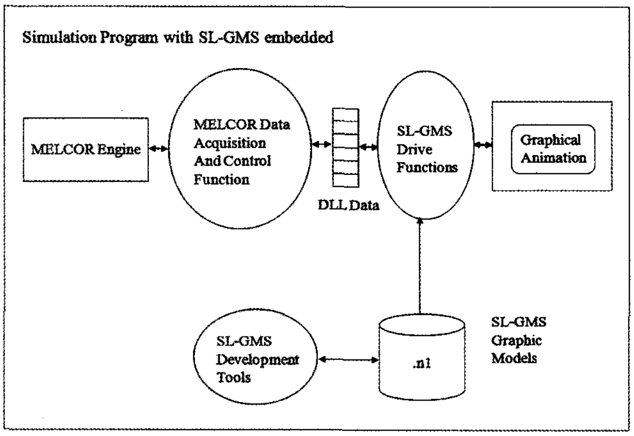


Fig. 1. Design Concept of SATS Using SL-GMS

MELCOR code consists of more than 20 packages like CVH/FL, COR, etc. For example, the CVH/FL package performs thermal hydraulic calculations of control volumes and pipelines, and the COR package calculates properties of the reactor core. MELCOR stores the calculation results of all packages to specially defined array variables, which are XREALX, INTEGE, CHARAC, and LOGICA, according to their parameter type. Among these database variables, INTEGE, CHARAC, and LOGICA are named common block variables, while XREALX is defined as an equivalence variable of a blank common block variable DREALX. Each package also defines several index variables to find the value of an arbitrary package variable in the database arrays. In making the DLL, the global database variables and index variables should be defined in the DLL, to be used by both MELCOR and SATS. Consequently, the DLL consists of block data and functions. However, since XREALX is a blank common block variable, which should be located in the lowest address of the MELCOR process, it is impossible to map a DLL variable to XREALX. In order to resolve this problem, DBREAL is changed to a named common block variable.

2.2 Design of Graphic Displays

SL-GMS is a commercial development tool for the development of graphical application software in the area of process control, factory automation, network management, transportation, trade business, and so on. SATS uses the SL-GMS to display the nuclear plant's dynamic data. The basic object of the SL-GMS is a screen display object, called a model, which can be made by the SL-Draw graphic object editing tool contained in the SL-GMS tools. In order to develop an application program using the SL-GMS models, a driver program that controls the dynamic properties of the models should be built. Fig. 1 schematically illustrates the roles of the driver and SL-GMS model roles in SATS.

Besides accident simulations, SATS can also be used for severe accident management and training purposes. While there are various kinds of nuclear plant operator aid systems, they can be broadly classified as either plant safety parameter display, knowledge based accident diagnosis or electronic procedure support systems. In general, most operator aid systems have more than two of the functions listed above, and thus the common operator aid system is a composite of these systems. In the case of SATS, it is designed to accomplish these operator aid functions, and therefore its detailed functions and necessary displays were composed to satisfy the following:

- Virtual plant and severe accident simulation

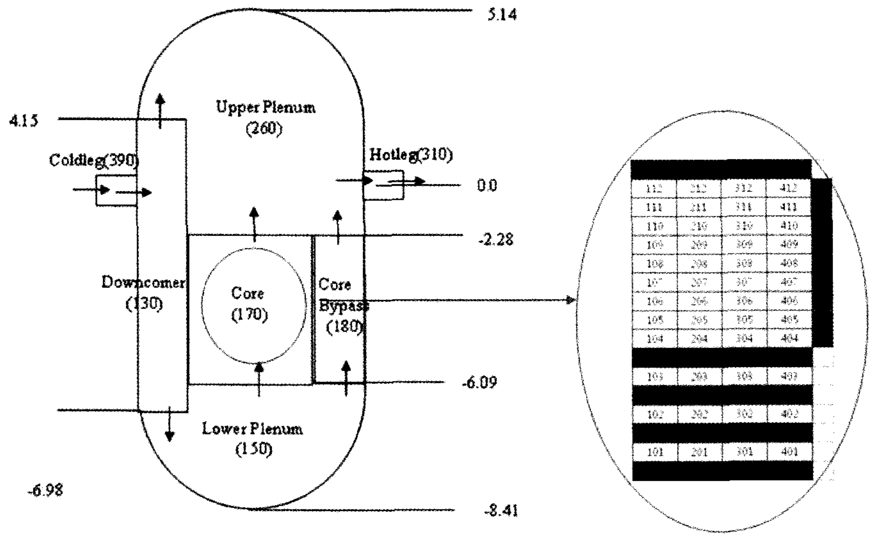


Fig. 2. Reactor and Core Nodalization for Graphic Animations

- Safety parameter display of virtual plant
- Simulation of accident mitigation using electronic procedures

For description of virtual plant behavior in a postulated severe accident scenario, the display windows of the SATS were designed to show thermal hydraulic (T/H) phenomena and chemical/ mechanical behavior of the containment systems. In order to give more efficient information about the accident status, the detailed display windows were designed to show water levels of the reactor coolant system, the reactor core temperature distribution, core melting and relocation sequence, release and transportation of fission products, core concrete interaction, engineering safety system status, and so on. In animating the behaviors of the plant's equipment and pipelines, T/H properties of control volume nodes are used to modify the dynamic properties of their corresponding SL-GMS models. In Fig. 2, the control volume nodes of the reactor and the cells of the reactor core used in the animation are shown for a clear explanation.

2.3 Design for Accident Management and Training

To efficiently support severe accident management activity, a SPDS (safety parameter display system) for a severe accident was designed. In the case of a Korean standard nuclear plant, a CFMS (Critical Function Monitoring System), which is a kind of SPDS, is being operated for maintenance and recovery of critical safety functions such as reactor core reactivity control, reactor coolant system (RCS) pressure control, RCS inventory control, and core heat removal. Although it is desirable to use the same type of SPDS for severe accidents, there are difficulties in using the CFMS as a severe accident SPDS, since it is designed to handle emergency information before core damage. There is a basic difference between the two systems. The primary objective of the CFMS is to prevent core damage, whereas the primary objective of a severe accident SPDS is to restrain radiation release. Thus, in order to meet these different objectives, there are numerous differences in safety parameters and available methods. The designed SPDS displays twelve safety parameters and alarms that are helpful to the operator with respect to accident diagnosis and decision-making. Table 1 is a list of the alarm parameters, instruments, monitoring objectives, and related strategies.

In order to simulate establishment and execution of an accident mitigation strategy through the SATS and an electronic SAMG linkage, the SAMG module was designed to provide GUI functions for SAMG, a strategy flow diagram, strategy establishment, and success path choice, while the SATS was designed to provide operation functions of control equipment needed to accomplish strategy execution. GUI functions needed for SAMG activities were partly established in an electronic SAMG module, HyperKAMG. (See Fig. 3)

2.4 Design of Control Devices

For a training simulator, control devices should be able to change the accident progression by manipulating several valves and/or pumps during an accident simulation. Basically, the MELCOR code does not provide interactive control functions during its simulation process. Furthermore, changing the current control options of control devices cannot be done quickly. If a MELCOR user wants to change the current control options, the user should finish the current simulation process first. should then modify the current CF package input lines with new control options, and finally restart the simulation process with the modified CF package input.

On the other hand, the restart information is saved

Table 1. List of Severe Accident Alarm Parameters

Safety Parameter	SAMG	Contents	Monitoring Objective	Instrumentation	Measure	Ref.Value
SG Pressure	SAG-01	Depressurize SG	FW availability SG tube rupture	4 pressure gauges / SG	ADV MSIV, MSSV	63% NR
RCS Pressure	SAG-02	Depressurize RCS	RCS broken SI availability	Back RCP pressure gauge PZR Pressure	TB bypass Vv SDS Vv	20.2 MPA
Core Exit Temperature	SAG-03	Inject into RCS	Core damage	Hot-leg thermometer	HPSI, LPSI Pp Charging Pp CSP	644.1°K
Containment Level	SAG-04	Inject into CTMT	Equipment flooding ECCS recir. mode	Water pressure difference		17 % WR
Radioactivity Release	SAG-05	Control FP release	CTMT rad. level Seal table Rad. level	CTMT rad. detector Local rad. detector	CTMT fan cooler	0.5 mSV/hr
Containment Pressure	SAG-06	Control CTMT condition	CTMT integrity	NR P. gauge WR P. gauge	CTMT fan cooler CSP	1.9 psig
Hydrogen in CTMT	SAG-07	Control H_2 concentration in CTMT	H_2 burn H_2 explosion	H_2 detector	H_2 recombiner H_2 ignitor Cavity fan SDS bleed Vv	10%

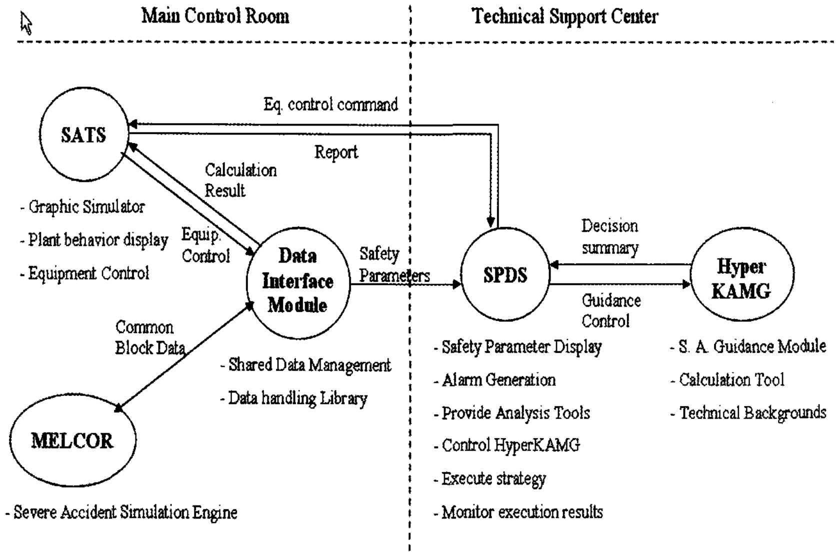


Fig. 3. Conceptual Diagram of Accident Mitigation Simulation

only at a specified time due to the restart file size. Therefore, it is impossible to change the control options at every necessary time in this manner. Moreover, control options cannot be changed after MELCOR code execution. Therefore, as a training simulator, SATS needs a flexible control capability such that the user can operate any control equipment without the above restrictions.

In building interactive control devices, simply putting MELCOR control parameters in the DLL shared memory space, as shown in Fig. 1, solves the above problems. If the control parameters are located in the DLL, then SATS can change these parameters at any time. However, almost all control parameters are busy during the simulation because of their pre-assigned missions. Simply changing these reserved control parameters often has no effect, because the system code will reset these parameters according to parametric conditions set at the start of the simulation.

For example, suppose a valve V1 is located on a flow line FL01 connecting two control volumes CV01 and CV02, and V1 is being controlled by a control parameter CF01 such that whenever the primary pressure is below a reference pressure P0, then CF01 is set to be zero by the system code causing the valve V1 to be closed. In this case, if the user has opened valve V1 of SATS via mouse clicking, SATS will change the CF01 to be 1. However, the system code MELCOR immediately compares the current pressure with the reference value P0; if the current pressure is below P1, then the system code will change CF01 to be zero immediately, causing valve V1 to be closed again. To prevent these kinds of control failures, a new valve V2 controlled by CF02 is designed and installed on the FL01 in series or in parallel, and then the FL01 flow is determined by CF01+CF02 or CF01*CF02. The user can then control the flow of FL01 by clicking valve V2 of SATS without interrupting V1's control logic.

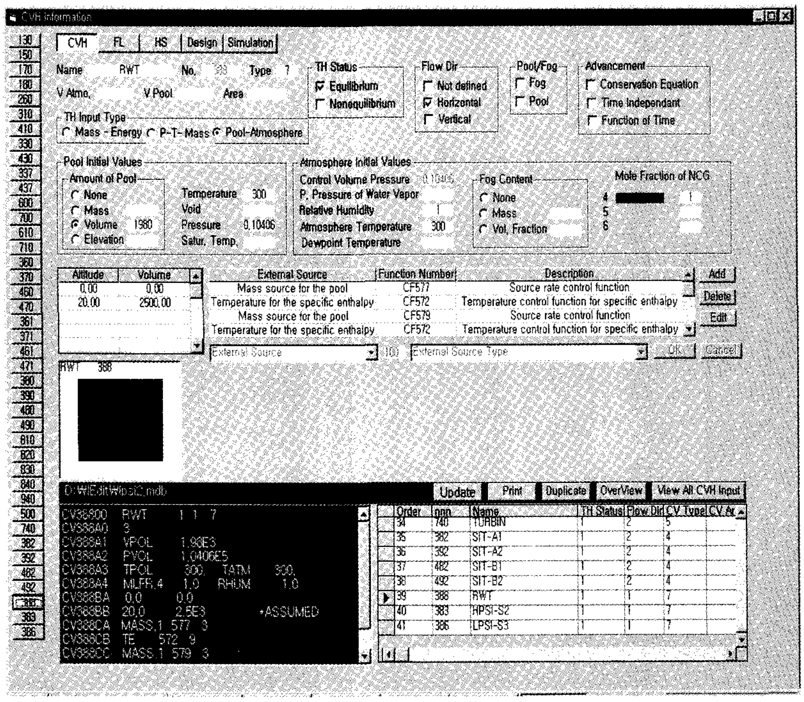
3. MAIN FEATURES

All functions of SATS are available through its main menu, having top menu items File, Pre-Process, Simulation, Replay, View, Tools, and Help. Prior to an accident simulation, the first restart file should be generated using the Pre-Process menu, which invokes the MELGEN pre-processor.

3.1 Accident Simulation

Severe accidents are often classified by their initiating events, as Station Black Out (SBO), Loss of Feed Water (LOFW), Steam Generator Tube Rupture (SGTR), and so on. SATS uses its own scenario input to simulate these severe accident scenarios. For various kinds of accident simulation, SATS provides a scenario editing tool, IEDIT. Using IEDIT, detailed information of the control volume, flow line, core, and control functions defined in the scenario input can be easily displayed and edited. The IEDIT input editing tool is available through a submenu item, "Load Input File", under the "File" top menu. (Fig. 4)

After selection of a scenario input file from the "Simulation" top menu, it is possible to activate the MELCOR engine. Using submenu items in the "Simulation" menu, a user can pause, resume, and stop the simulation at any time. The pause and resume functions are especially helpful to trainees in a mitigation strategy establish step. In addition, simulation results could be saved for a fast review using the "Replay" menu. Fig. 5 shows the appearance of SATS, including the main display window, detailed equipment display windows, and a trend graph. The upper left window is the main display window,



Name RWT No. 388 Type 7

V Atmo. V Pool Area

TH Status: ☑ Equilibrium ☐ Nonequilibrium

Flow Dir: ☐ Not defined ☑ Horizontal ☐ Vertical

Pool/Fog: ☐ Fog ☐ Pool

Advancement: ☐ Conservation Equation ☐ Time Independant ☐ Function of Time

TH Input Type: ○ Mass - Energy ○ P-T-Mass ● Pool-Atmosphere

Pool Initial Values — Amount of Pool: ○ None ○ Mass ● Volume 1980 ○ Elevation

Temperature 300
Void
Pressure 0.10406
Satur. Temp.

Atmosphere Initial Values:
Control Volume Pressure 0.10406
P. Pressure of Water Vapor
Relative Humidity 1
Atmosphere Temperature 300
Dewpoint Temperature

Fog Content: ○ None ○ Mass ○ Vol. Fraction

Mole Fraction of NCG: 4 1; 5; 6

Altitude	Volume
0.00	0.00
20.00	2500.00

External Source	Function Number	Description
Mass source for the pool	CF577	Source rate control function
Temperature for the specific enthalpy	CF572	Temperature control function for specific enthalpy
Mass source for the pool	CF579	Source rate control function
Temperature for the specific enthalpy	CF572	Temperature control function for specific enthalpy

```
CV38800  RWT      1 1  7
CV388A0  3
CV388A1  VPOL     1.98E3
CV388A2  PVOL     1.0406E5
CV388A3  TPOL     300.   TATM     300.
CV388A4  MLFR.4   1.0    RHUM     1.0
CV388BA  0.0      0.0
CV388BB  20.0     2.5E3            *ASSUMED
CV388CA  MASS.1 577  3
CV388CB  TE     572  9
CV388CC  MASS.1 579  3
```

Order	nnn	Name	TH Status	Flow Dir	CV Type	CV Ar
34	740	TURBIN	1	2	5	
35	382	SIT-A1	1	2	4	
36	392	SIT-A2	1	2	4	
37	482	SIT-B1	1	2	4	
38	492	SIT-B2	1	2	4	
39	388	RWT	1	1	7	
40	383	HPSI-S2	1	1	7	
41	386	LPSI-S3	1	1	7	

Fig. 4. IEDIT Scenario Input Editing Module

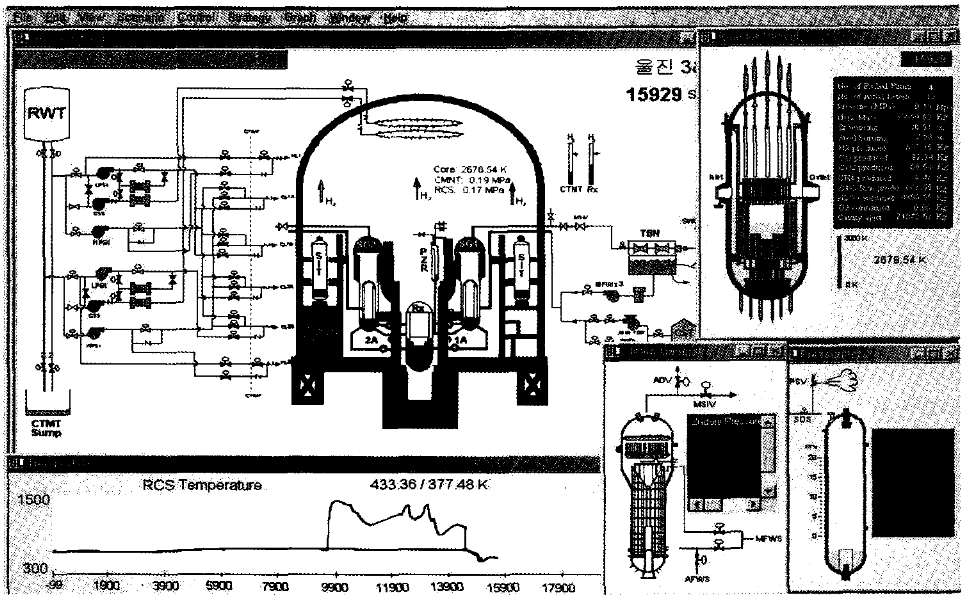
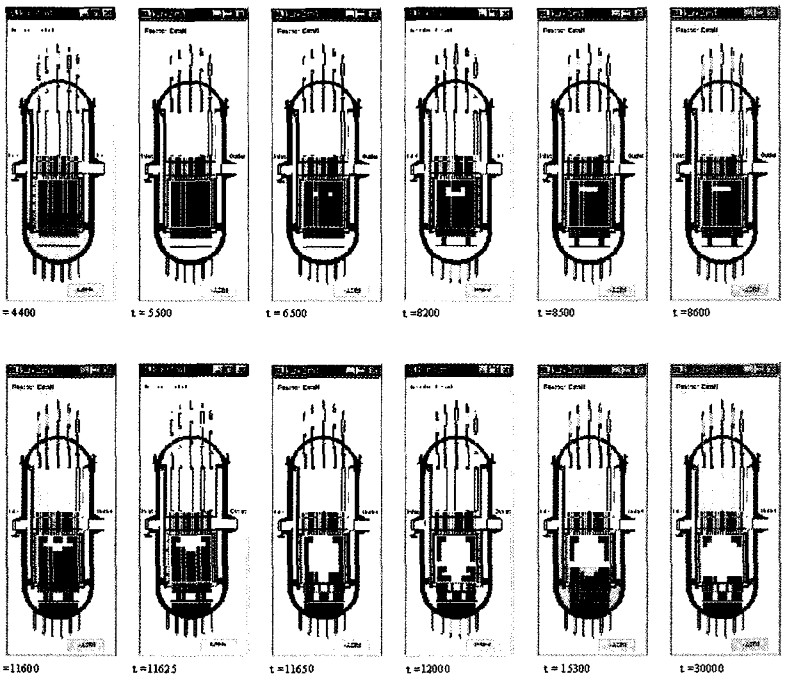


Fig. 5. Main and Detail Views of SATS


t=4400 t=5500 t=6500 t=8200 t=8500 t=8600

t=11600 t=11625 t=11650 t=12000 t=15300 t=30000

Fig. 6. Graphic Animation Showing Core Melting and Relocation Process

showing an overview of the KSNP containment, and its subsystems. The main window overview shows a three-loop RCS having one reactor and two steam generators. It also shows pipe and instruments drawings (P&IDs) of the high pressure/low pressure safety injection system (HPSI/LPSI) and feed water (FW) system. Images of main view equipment and pipelines are continuously updated by the MELCOR simulation data, showing their current operation status.

Detailed view windows of the reactor, steam generator (SG,) and pressurizer (PZR) are shown in the right popup windows of Fig. 5. They appear when corresponding equipment is mouse-clicked in the main view. These detailed view windows show the coolant water level, temperature, and inner pressure of the corresponding equipment. These kinds of images could provide insight into the equipment's behavior to the user that would otherwise be impossible to ascertain. For example, grasping the reactor water level with only MELCOR data is not easy, because MELCOR calculates only the water levels of control volumes, which are part of the reactor. On the other hand, the graph in the left lower part of Fig. 5 shows the user a trend graph of the selected parameter among the twelve severe accident safety parameters of the SPDS.

Severe accidents are different from a design basis accident (DBA). When a DBA becomes a severe accident, the reactor water is dried out, exposing the core to the air. As the core temperature increases to exceed 2000°K, the melting point of the fuel pallet, the core begins to melt and the molten debris falls to the lower plenum of the reactor to form a molten pool. The molten debris in the pool is then relocated as it is cooled down. SATS has a graphic animation tool to show the above core melting and relocation process by using mass and temperature information of UO2 in the core cells and lower plenum. In Fig. 6, core melting and relocation process images generated by SATS during a TLOFW simulation are shown.

3.2 Safety Parameter Monitoring

SPDS, a sub-module of SATS, is developed to display severe accident specific safety parameters. Currently, the SPDS uses MELCOR simulation parameters instead of real plant signals. The developed SPDS has a simple display, showing information on necessary parameters and alarms needed in the SAMG. execution. The seven alarms are located on the top of the SPDS display panel. The color of these alarms changes to blue, yellow, and red as the seven parameters of Table 2 vary.

As shown in Fig. 7, the SPDS has twelve small windows to draw safety parameters graphs, showing the current value together with the one hour trend. The twelve safety parameters are RCS pressure, SG water level, containment pressure, containment temperature, containment water level, containment hydrogen concentration, and radiation in the containment.

Table 2. List of Implemented Control Devices

	Control Device	Operation
Primary	Hi Press Safety Injection PP	Start - Stop
	Lo Press Safety Injection PP	Start - Stop
	SDS VV	Jog Dial
	PZR Aux. Spray PP	Open - Close
Secondary	AFW Flow Control VV	Open - Close/Mod
	AFW PP	Start - Stop
	MFW PP	Start - Stop
	MSIV	Open - Fast Close - Slow Close
	SG ADVs	Open/Mod - Close
	Steam Bypass VV to CDs	Open/Mod - Auto - Close
Containment	SPRAY PP	Start - Stop
	Fan Coolers (Low Speed)	Lo Start - Stop
	Fan Coolers (High Speed)	Hi Start - Stop
	H2 Igniter	On - Off

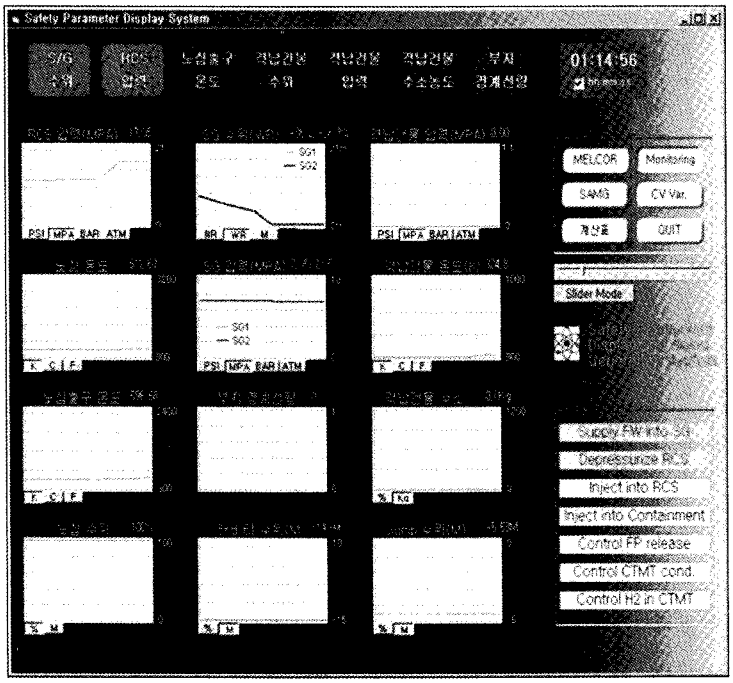


Fig. 7. Severe Accident Safety Parameter Display System (SPDS)

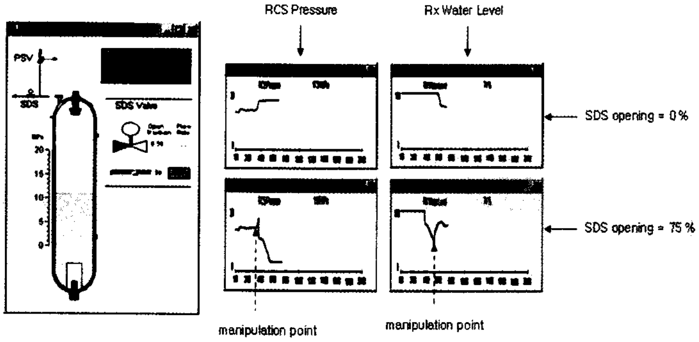


Fig. 8. SDS Valve Control Panel and Control Results

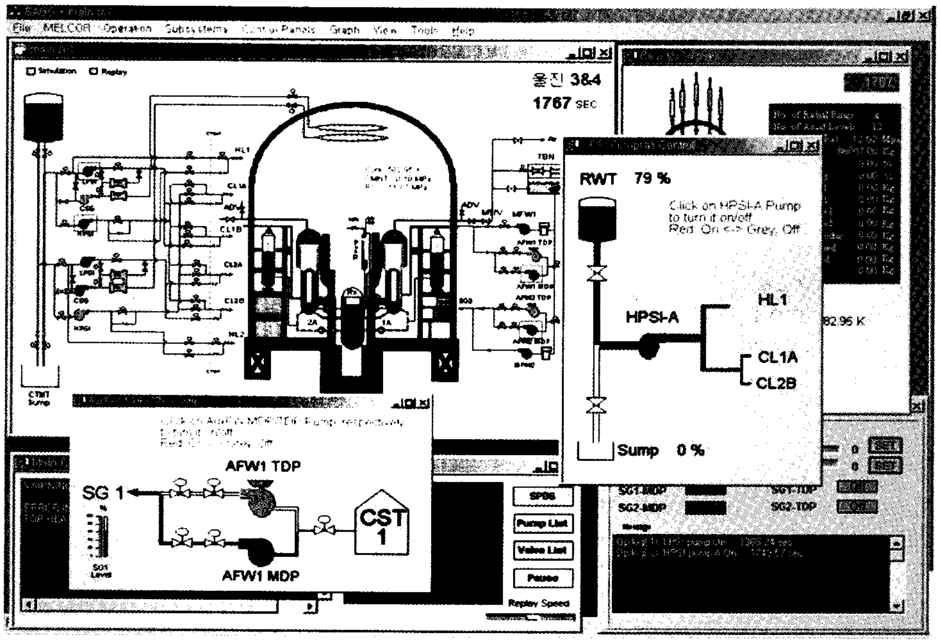


Fig. 9. Control Device Panels for Accident

3.3 Interactive Control

Table 2 lists the control devices of SATS. Some of the control devices in the SAMG such as the charging pump, start-up (STUP) FW pump, CEDM fan, and hydrogen recombining device are not implemented after practical considerations.

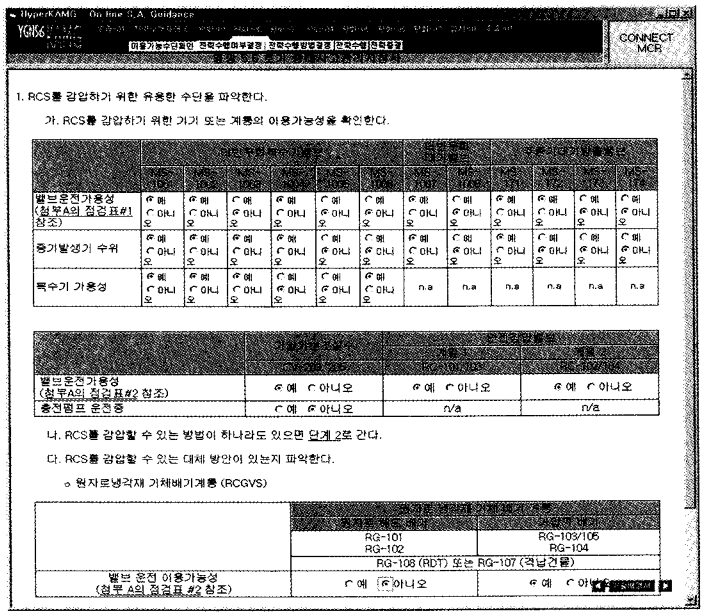
SATS has several interactive control device panels in order to show related P&IDs and necessary information for device manipulation. A control device panel appears when the corresponding device in the main view is mouse-clicked. Another purpose of this two step control is to minimize unintended mouse mistakes. In Fig. 8, the left side window is a shutdown depressurize system (SDS) valve manipulation panel, and the four windows on the right side show how the RCS pressure and RCS water level change when the SDS valve opening is changed from 0% to 75%.

Now the LPSI and aux feed water (AFW) control panels are introduced briefly, as they are the most frequently used devices. The main view of SATS consists of the containment and two P&ID images located at the left and right side, showing the status of the safety injection system and feed water system, respectively.

Fig. 9 shows the activated LPSI control panel and AFW control panel in the main view. As soon as the user mouse-clicks a control device, the device is marked by a blue rectangle and its control device panel appears. The device panels show necessary information to manipulate the control device. Note that the two available LPSI and HPSI pumps are activated, but there are no LPSI flows because of high RCS pressure. Also, Fig. 9 shows that two steam generators are supplied water by AFW manual driven pumps.

3.4 Training

When a beyond DBA occurs, the whole plant safety will depend completely on the operators' behaviors. If



1. RCS를 감압하기 위한 유용한 수단을 파악한다.

가. RCS를 감압하기 위한 기기 또는 계통의 이용가능성을 확인한다.

	[illegible]						[illegible]		[illegible]			
	MS-1001	MS-1002	MS-1003	MS-1004	MS-1005	MS-1006	MS-1007	MS-1008	MS-171	MS-172	MS-173	MS-174
밸브운전가용성 (첨부A의 점검표#1 참조)	● 예 ○ 아니오	● 예 ○ 아니오	○ 예 ● 아니오	● 예 ○ 아니오	○ 예 ● 아니오	○ 예 ● 아니오	● 예 ○ 아니오	○ 예 ● 아니오	● 예 ○ 아니오	● 예 ○ 아니오	○ 예 ● 아니오	○ 예 ● 아니오
증기발생기 수위	● 예 ○ 아니오	● 예 ○ 아니오	● 예 ○ 아니오	● 예 ○ 아니오	○ 예 ● 아니오	○ 예 ● 아니오	● 예 ○ 아니오	○ 예 ● 아니오	● 예 ○ 아니오	○ 예 ● 아니오	○ 예 ● 아니오	○ 예 ● 아니오
복수기 가용성	● 예 ○ 아니오	● 예 ○ 아니오	● 예 ○ 아니오	○ 예 ● 아니오	○ 예 ● 아니오	● 예 ○ 아니오	n.a	n.a	n.a	n.a	n.a	n.a

	[illegible]	[illegible]	
		계통 1	계통 2
	[illegible]	[illegible]	[illegible]
밸브운전가용성 (첨부A의 점검표#2 참조)	● 예 ○ 아니오	● 예 ○ 아니오	● 예 ○ 아니오
충전펌프 운전중	○ 예 ● 아니오	n/a	n/a

나. RCS를 감압할 수 있는 방법이 하나라도 있으면 단계 2로 간다.

다. RCS를 감압할 수 있는 대체 방안이 있는지 파악한다.

○ 원자로냉각재 기체배기계통 (RCGVS)

	[illegible]	
	[illegible]	[illegible]
	RG-101 RG-102	RG-103/105 RG-104
	RG-108 (RDT) 또는 RG-107 (격납건물)	
밸브 운전 이용가능성 (첨부 A의 점검표 #2 참조)	○ 예 ● 아니오	● 예 ○ 아

Fig. 10. Equipment Check List in Electronic Severe Accident Guidance Module, HyperKAMG

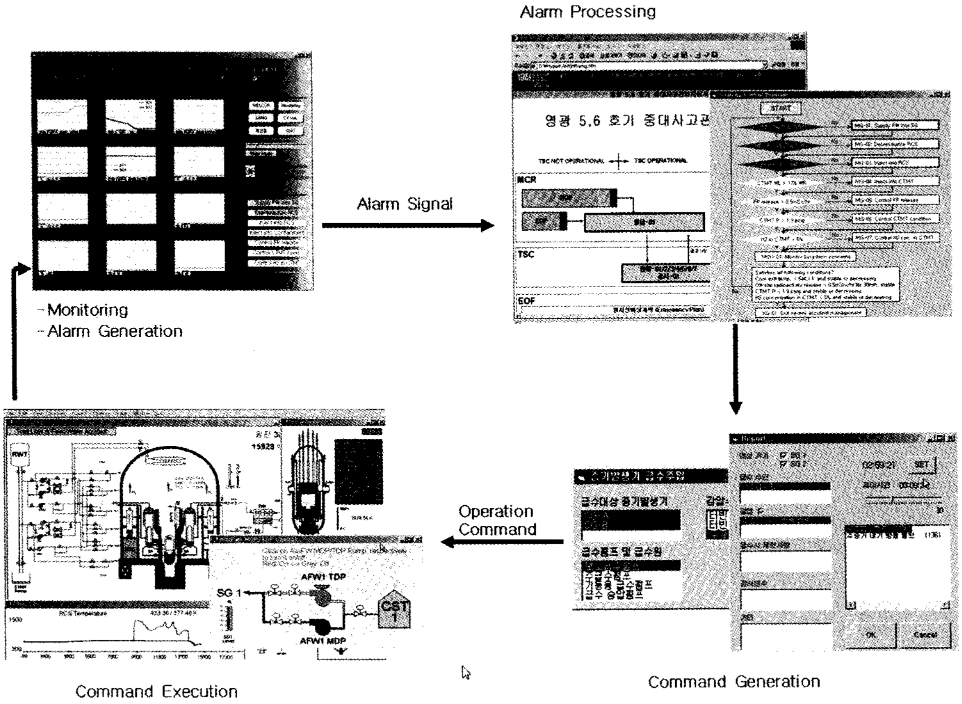


Fig. 11. SATS-HyperKAMG Linkage for Severe Accident Training

the operators do not recover the plant, then the plant may be severely challenged and radioactivity may be released from the damaged fuels to the containment.

Basically, SATS and HyperKAMG were developed to support decision-making at the technical support center (TSC) for accident mitigation. We made an accident mitigation training system by linking functions of these two systems. The SATS-HyperKAMG system can provide TSC members with virtual environments where they can experience various kinds of severe accidents and practice mitigation strategies.

Here, we introduce an electronic SAMG module, HyperKAMG. It has full contents of KSNP SAMG, including all emergency guidance, strategy control diagram, mitigation guidance, exit guidance, technical background, equipment checking tables, and calculation aid. The SAMG has seven mitigation strategies (MG), and each mitigation strategy consists of five steps, available equipment check, strategy confirmation, executing methods decision, strategy execution, and strategy exit.

While SAMG has all necessary procedures to mitigate severe accidents, the procedures are not complete. Because of uncertainties in severe accident phenomena, only recovery guidelines are developed instead of detailed recovery procedures. Besides providing SAMG content, HyperKAMG provides several tools that are helpful to TSC workers. GUI tools to find the success path and to calculate negative and positive impacts of a particular strategy have been developed or are under development as aid tools. These aid tools could supplement SAMG's incompleteness and they could help TSC workers to complete the SAMG procedures easily.

Fig. 11 shows the SATS-HyperKAMG training system configuration. In this training system, SATS plays a role of a virtual plant experiencing a severe accident, and the SPDS monitors safety parameters and generates several alarms. The right side of the figure is the HyperKAMG screen shots, showing TSC's strategy execution procedures. According to the accident parameters and strategy control diagram, HyperKAMG automatically opens a necessary strategy start page for the strategy accomplishment.

After following the five strategy execution steps, a trainee will generate a success path for the strategy execution. Finally, the generated success path and operation commands are sent to SATS for the next simulation.

Even though trainees using our system can acquire knowledge of several important severe accident phenomena and SAM effects through SAM activity practice, functions such as multi-user interface, real-time, and socket to the DBA training system must still be developed for practical usage at site training centers.

4. APPLICATION RUN

Total loss of feed water (TLOFW) is one of the representative accidents causing core damage due to the loss of all feed water for steam generator cooling. Fig 12 is an event tree (ET) prepared for TLOFW application runs, whose three heading events are secondary side water injection, RCS depressurize, and RCS injection, in order. Branches of the scenario mean success or failure of the heading events. The lowest scenario #6 in the ET is a base scenario of TLOFW, where all the heading events fail. On the other hand, first scenario #1 is a TLOFW scenario, where all the heading events are successful. In this section, the original TLOFW scenario #6 is simulated first, and then the scenario is changed to #1 scenario by using control devices of SATS.

The original TLOFW scenario is scenario #6. In this TLOFW scenario, reactor trip occurs at zero second, due to a SG low level signal or PZR high pressure signal. SG dry-out, core uncovery, melting and relocation, and lower head penetration then occur in order. This scenario can be shown with a prepared basic TLOFW scenario input of SATS. The simulation results are summarized in Table 3.

For the next simulation, we use the same scenario input file. During the simulation, some control devices of SATS are used to change scenario #6 to scenario #1. Here we assumed that the AFW system will be repaired after ten thousand seconds, which was unavailable at the beginning of the accident. The recovered AFW system will be used in the first accident mitigation strategy. In addition, we also assume that only the SDS valve is available for accident mitigation strategy 2. (See Table 1)

Since we use the same scenario input file as #1, the accident progression of scenario #6 is the same as that of scenario #1 before 10000 sec. At a core exit temperature 361.1°C at 10400 sec, SAMG starts and establishment of TSC starts. Since about 20 minutes is required before TSC establishment, MCR operators follow the emergency

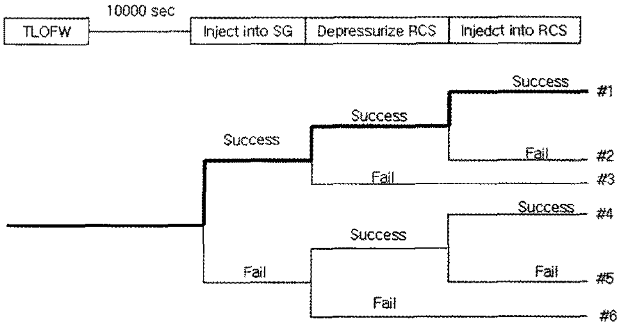


Fig. 12. TLOFW Event Tree for an Example Application of SATS

Table 3. TLOFW Milestones (Base Case)

Time (s)	Important Phenomena
0	Reactor trip
3,000	Steam generator dryout RCS pressure increase CTMT pressure increase
6,190	Start core uncovery
9,540	Core dryout
10,400	Core exit temp. > 644.1°K
12,875	Core melting and relocation
13,259	Lower head penetration
13,597	SIT injection

guidance before the TSC establishment. At 11600 sec after TLOFW, TSC is established and MG-01 is executed by opening the MSADV valve and activating AFW pumps. The effect of MG-01 is identified quickly by checking the core exit temperature drop under 361.1°C at 11800 sec, and then the HyperKAMG module indicates start of MG-02 to recover the RCS inventory. According to the HyperKAMG module, MG-02 is executed by opening the SDS valve at 11900 sec. Table 4 lists phenomena and their occurrence times for scenario #1.

Table 4. TLOFW Milestones (after Operation)

Time(s)	Important phenomena	Operation
0	Reactor trip	
3,000	Steam generator dryout RCS pressure increase CTMT pressure increase	
6,190	Start core uncovery	
9,540	Core dryout	
10,400	Core exit temp. > 644.1°K	
11,600	Monitor Strategy Control Diagram	
11,650	Execute SAG-01 AFW restart	AFW on
11,800	Core exit temp. < 644.1°K	
11,900	Recover RCS inventory Execute SAG-02	SDS VV open

Assumptions:
After 2hr of TLOFW, AFW is repaired
Only SDS Valve is available for RCS depressurization

Fig. 13 shows the safety parameters at 11,000 seconds of scenario #6, showing that the core temperature increases continuously and that steam generator water is dried out, which means the accident is in the process of becoming a severe accident. Fig. 14 shows the safety parameters at 14,100 seconds of scenario #1, showing the accident mitigation activities listed in Table 4. After repair of the SG aux feed water system, the secondary side water level is recovered, and the primary side pressure is lowered by opening the SDS valve. Finally, the low pressure safety injection system is started due to the low pressure, and the core status becomes stable.

5. SUMMARY

In this paper, technical specifications for the development of a severe accident training simulator are presented. The developed severe accident training simulator shows a number of important severe accident phenomena and nuclear plant behaviors dynamically. Moreover, during a simulation, the simulator continuously generates plant behavior and accident progression images by using a MELCOR engine. On the other hand, the simulator also provides several interactive control devices, which are helpful to assess the results of a particular accident

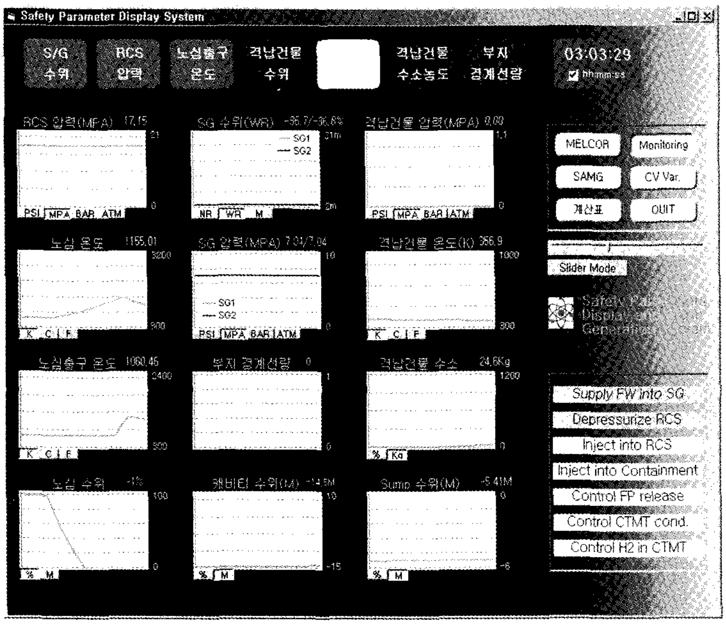


Fig. 13. SPDS Screen Showing the Performance of the Control Device of SATS - TLOFW-#6 (11,000 sec)

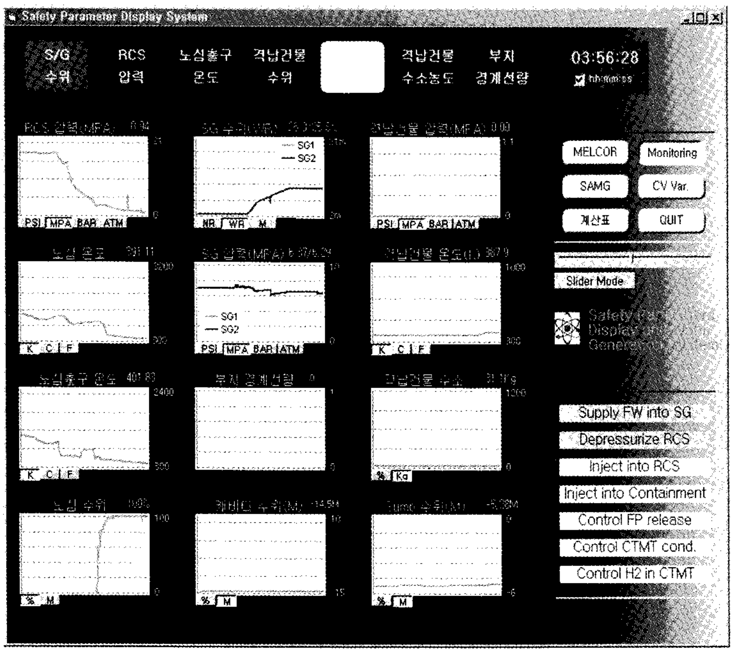


Fig. 14. SPDS Screen Showing the Performance of Control Device of SATS - TLOFW-#1 (14,100 sec)

management behavior with respect to their impact on the accident progression.

In the description of the SATS development methodology, a simple and direct DLL data communication method is presented. Using the DLL, the method to build the simulator's control device is also presented. Although the method uses the MELCOR code and the SL-GMS graphic tool, it can be applied to any other codes and other graphic tools.

Finally, a SATS-HyperKAMG linked training model is suggested for accident mitigation training. The electronic SAMG module HyperKAMG and its functions are introduced. The SATS-HyperKAMG capabilities and required functions as a training tool are discussed. The performance of the SATS-HyperKAMG system is shown through application runs.

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