Development of Computerized Severe Accident Management Guidelines of AP1000 Nuclear Power Plant

Gang Chen[1,2], Shuang Xiao[1], Haidan Wang[1], Yiqiang Xiong[1] and Yixue Chen[1]
[1]State Nuclear Power Software Development Centre, South Side of Future Science & Technology Park, Changping District, Beijing, China
[2]National Energy Key Laboratory of Nuclear Power Software, Beijing, China

Keywords: Nuclear Power Plant, Computerized Severe Accident Management Guidelines, AP1000.

Abstract: Nuclear Power is considered to be one of the solutions to fulfil the increasing need of clean energy in China. Making use of this clean energy can help reduce the consumption of fossil energy, which could enhance the surrounding areas by preventing the environment from harmful air pollution. However, the consequence of severe accident of nuclear power is unbearable, such as Chernobyl and Fukushima Accidents. So as to improve the safety of nuclear power, the severe accident shall be managed in case to reduce the negative impacts to the environment and people health. This paper introduces the Severe Accident Management and Emergency Response System (SAMERS), which aims to help the operators and technicians deal with the severe accidents. Especially, the development of Computerized Severe Accident Management Guidelines (CSAMG) is described in detail, which is a module of SAMERS. CSAMG is based on the AP1000 severe accident management guidelines, which could enhance the operator performance during severe accident.

1 INTRODUCTION

Due to the rapid development of Chinese economics and the demand for more environmentally friendly energy, China has issued an ambitious program of nuclear power development. By 2020, the nuclear installation will reach 40 GW (CNDRC, 2007), which means many nuclear power plants will be built in the next few years. A big part of the new-built nuclear power plants (NPPs) will be of AP1000 type, including Sanmen and Haiyang NPPs. Fukushima accident has drown people’s attention to the severe accident consequence. After Fukushima accident, all NPPs in China planned to enhance their capability of severe accident management and emergency response, as required by the regulation organization. One way to improve the severe accident management capability is to investigate the scenario and phenomena of accident to improve the calculation of severe accidents. The other efficient way is to employ the computer-based procedure system rather than the paper-based procedures in the implement of severe accident management guidelines (Robert et al., 2009).

To enhance the safety of nuclear power plant, especially for the AP1000 type NPPs during severe accidents, Severe Accident Management and Emergency Response System (SAMERS) is designed to support the operators and technicians during the severe accident and emergency conditions. It is supposed to be able to monitor the plant status and to simulate the accident process in advance. Then it could show the plant response to the mitigation intervention, and evaluate the accident consequence. Computerized Severe Accident Management Guidelines (CSAMG) is a relatively independent module of SAMERS. The main function of CSAMG is to monitor the plant status and to provide the proper advice to mitigate the accident effectively. The ultimate objective of SAMERS and CSAMG is to apply to NPPs for accident mitigation and emergency response. But in the near term, the application of SAMERS and CSAMG would be used to train the new operators and technicians to enhance their understanding of severe accident progress.

2 SAMERS

SAMERS consists of 3 subsystems:

(1) Accident Analysis and Prediction Subsystem (AAPS)

Chen G., Xiao S., Wang H., Xiong Y. and Chen Y..
Development of Computerized Severe Accident Management Guidelines of AP1000 Nuclear Power Plant.
DOI: 10.5220/0005560901990204
In *Proceedings of the 5th International Conference on Simulation and Modeling Methodologies, Technologies and Applications* (SIMULTECH-2015), pages 199-204
ISBN: 978-989-758-120-5

(2) Plant Status Evaluation Subsystem (PSES)

(3) Plant Information and Interface Display Subsystem(PIDS)

The Client/Server architecture is employed for its futures of high stability, intensive interaction, mass data processing and communication. The 4-tier architecture of SAMERS is shown in figure 1.

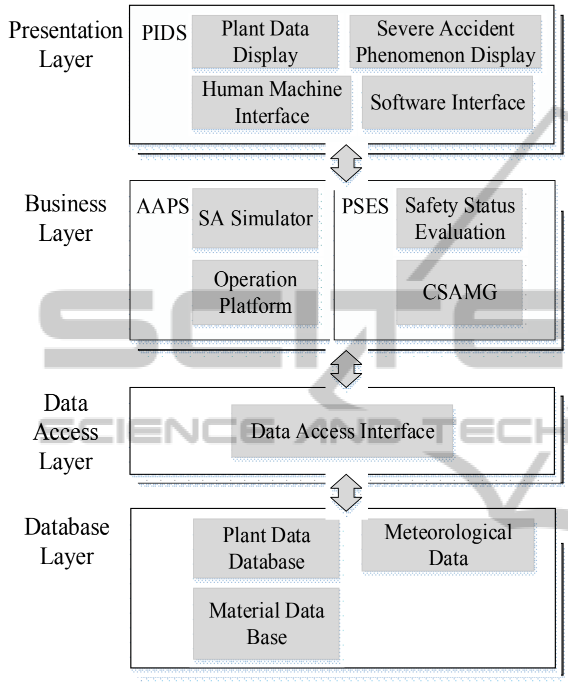

Figure 1: The 4-tier architecture of SAMERS.

2.1 AAPS

The main function of AAPS is to simulate the severe accident scenario by using the severe accident simulator. The severe accident simulator adopts the Severe Accident Source Term (SAST) code as the calculation engine. It could simulate in real-time scenario or faster-than-real-time scenario. When the SAMERS is connected to the NPP network, which is called on-line mode, the plant data that is transferred from the detectors on site could provide the initial conditions and boundary conditions for simulating. The AAPS could predict the scenario in advance, so the operators and technicians could figure out mitigation actions; also they could apply these actions to the simulator to make sure the impact is positive. Besides the on-line mode, the off-line mode of SAMERS is used only as a training system which means AAPS could provide a virtual reactor for the trainees to operate.

2.2 PSES

PSES consists of 2 major modules, one is safety status evaluation module; the other one is CSAMG. The safety status evaluation module is capable of evaluating several critical safety status such as the reactor core damage, containment hydrogen flammability and spent fuel pool status. These safety statuses are the uppermost issues in the plant operation. This module could offer the clear results of these safety evaluations, help the operators to decide the mitigation actions.

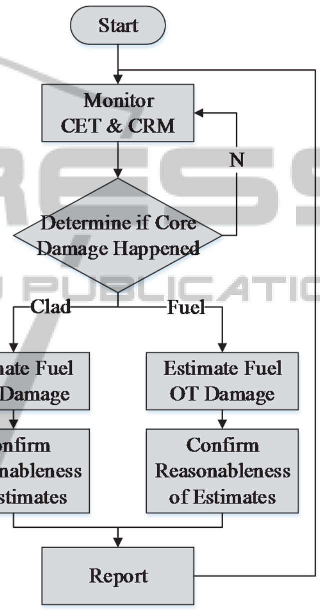

Figure 2: Flowchart of reactor core damage evaluation.

CSAMG is a support tool for the operators and technicians under the condition of severe accident. When linked to the plant database, it could monitor the parameters and automatically remind the operators of dangerous situations that need to be concerned. It also provides many mitigation advices. The function of CSAMG will be described in detail in the next chapter.

2.3 PIDS

PIDS is the user interface of SAMERS. It not only displays the real-time plant data, but also shows a severe accident phenomenon simulation, which helps users to understand the process taking place in a severe accident. The visual image of accident phenomenon is important for the trainees to learn the accident scenario. Furthermore, PIDS provide human machine interface which is used to manipulate the severe accident simulator, and all the software interfaces including CSAMG.

3 COMPUTERIZED SEVERE ACCIDENT MANAGEMENT GUIDELINES

Severe accident management guideline is a paper-based handbook for the NPP operators and technicians to consult when the accident happened. It requires the operators and technicians to be very familiar with its content so as to locate the information they need quickly. It would cost lots of time and energy to learn the guidelines during the training courses. And under the condition of severe accident, due to the tension and pressure of operators, they might be inefficient to look up through the handbook. Compared to the paper based procedures, Computerized Procedure System could improve the performance of operators in the procedure application (Lee et al., 2010). It also could reduce workload and save time during the accidents (Yuji et al., 1996).

To develop the CSAMG, firstly, the AP1000 SAMG is investigated to learn the work mode of operators and technicians during the accident; then the requirements are analysed to provide the design basis of CSAMG; next is the function design of CSAMG. At the same time the prototype of CSAMG is developed. At last is the test and validation. We are in the stage of function design and prototype development.

3.1 AP1000 SAMG

AP1000 SAMG consists of three major parts: (Zheng, 2012)

(1) Control Room Severe Accident Management Guidelines (CR SAMG);

(2) Technical Support Centre Severe Accident Management Guidelines (TSC SAMG);

(3) TSC Severe Challenge Response Guidelines (TSC SCRG).

The CR SAMG is guided by the control room, while the TSC SAMG and TSC SCRG are both guided by the TSC. The CR SAMG consists of two separate guidelines SACRG-1 and SACRG-2, which are defined by the status of the Technical Support Centre (TSC). SACRG-1 is the entry guideline from the AP1000 EOP to the SAMG. SACRG-1 includes many steps that are same as in the EOP. SACRG-2 is intended to enhance the cooperation of the control room and TSC. The primary responsibility of TSC is evaluating the plant status and recommending possible actions to mitigate the core damage. But if the core damage occurs before TSC is functional, the control room operators must response to the situation. SACRG-1 is the guideline for this condition. When the TSC becomes functional, the responsibility of severe accident management would pass to the TSC. The operators move to execute the SACRG-2.The control room operators will remain in SACRG-2 until the TSC decide to exit SAMG to other procedures.

The TSC SAMG and SCRG both can be divided into two sections: diagnostics and relative management strategies. These guidelines are used by the TSC to evaluate the plant status and to recommend the management strategies. The diagnostics consist of two parts: a Diagnostic Flow Chart (DFC) and a Severe Challenge Status Tree (SCST).

The DFC specifies several key parameters to monitor for diagnosis of plant status. The key parameters are monitored in a continual periodic way until all the parameters are in the safe region, so the plant could be declared to be safe. If one of the parameters is outside the range, the TSC should evaluate the need to implement strategies to make the parameter back into the safe range. The strategies are specified in a set of seven corresponding procedures called Severe Accident Guidelines (SAGs). It is worthwhile to notice that the mitigation strategies can have negative impacts. It is reasonable for the TSC to decide not implement any actions.

The SCST is the other tool for diagnosis of ongoing fission product releases and challenges to fission product boundaries. In the SCST, some key parameters are identified to be monitored too. The main difference between the DFC and SCST is the urgency of implementing the mitigation strategy. In the DFC, the impacts of the strategy should be evaluated by the TSC to determine whether to implement the strategy or not. But in the SCST, due to serious conditions, the strategy should be implemented immediately without the evaluation of the impact, because without the mitigation strategy, the fission product is about to release.

The seven SAGs corresponding to the DFC specify a systematic, logical evaluation of possible mitigation strategies to a given parameter. The SAGs helps the TSC staff identify the possibility of implement, balance of positive and negative impacts, symbol of the successful strategy, and long term concern of the strategy.

The four SCGs corresponding to the SCST are similar to the SAGs. The SCGs don't need the evaluation process of the positive and negative impacts. Through the SCGs, the TSC staff only needs to determine the most appropriate strategy, and to identify the successful symbol and long term concern of the strategy.

3.2 Requirement Analysis

Computerized procedure system based on computer information processing aims to assist operators and TSC members to monitor and control the implement of procedures. The ultimate goal of CSAMG is to assist the TSC members and operators execute the SAMG.

Basic functional requirements of CSAMG are similar to the CPS used on the AOPs and EOPs (Gang, 2013). But due to the difference between the AP1000 SAMG and other procedures, some requirements are special to the CPS of the AP1000 SAMG. The analysis could help the design to be more appropriate.

(1) CSAMG shall be capable of identifying the data availability and justify the data quality. The key parameter specified in DFC and SCST are very important for the TSC staff to evaluate the status of the plant. If the data is not available, the user should be warned by CPS, and the user should justify the procedure.

(2) CSAMG shall be capable of parallel monitoring plant status, especially the availability of systems and equipment (Park and Ahn, 2010). Any information of availability changed shall be displayed as warning to the operators and TSC technicians. The situation of severe accident is very complex, and the status of plant systems and equipment may change all the time. Since the availability of the systems and equipment affect the mitigation strategies directly, TSC technicians shall be aware of it timely. They need to re-evaluate the strategies already in use.

(3) CSAMG shall provide a convenient operation mode for the control room operators and TSC technicians to cooperate better. The information transferring and interaction process in the severe accident operation requires a convenient tool in CSAMG to make the communication and cooperation more effective. The communication function shall be combined with the parameter monitoring and strategies evaluating.

(4) CSAMG shall be capable of networking operation of multi-user from different locations to cooperate together. As mentioned above, the AP1000 SAMG is implemented by the main control room and TSC technicians. The TSC staff could be a group of experts from different places and they work on-line together with the control room to make the executing order. Furthermore, the CPS should guide the users to work together. Different users may have different tasks, and some of them could just evaluate the plant, and the others could take actions. Or the status of the plant is evaluated by different users, the final decision of implement the procedures are made by the joint discussion of these users.

(5) After one strategy is implemented, the long term impact of this strategy should be monitored. Due to the change of availability of systems and equipment, the old strategy may not be the most appropriate way to mitigate the accident. But to monitor every strategy that has been executed is difficult for operators or TSC technicians. CSAMG shall be capable of automatically monitoring the necessary information of implemented strategies. This function shall collaborate with the function of parallel monitoring.

(6) CSAMG shall provide easy access to the execution of mitigation strategies, such as provide the link to the operation interface of related systems and equipment. This function could accelerate the process of accident mitigation; especially benefit the management of fast-acting core damage sequence.

(7) CSAMG shall be capable of connecting to the severe accident simulator. The severe accident simulator could simulate different scenario to help the trainees manage severe accident and help validate the CSAMG. In the practical application rather than training application, severe accident simulator could also help the TSC technicians to evaluate the potential strategies by simulating them in advance and providing the impact to the plant.

3.3 Design Proposal

According to the requirement analysis of CSAMG, the CSAMG is designed to have two modes. One is on-line mode, connecting to the plant database or severe accident simulator for the use of accident mitigation and training; the other mode is off-line mode, which means it is independent from the data source, and it could be used by the students to learn the content of SAMG.

3.3.1 Architecture

The architecture of CSAMG is shown in figure 3. It is similar with the architecture of SAMERS, both of whom are client/server.

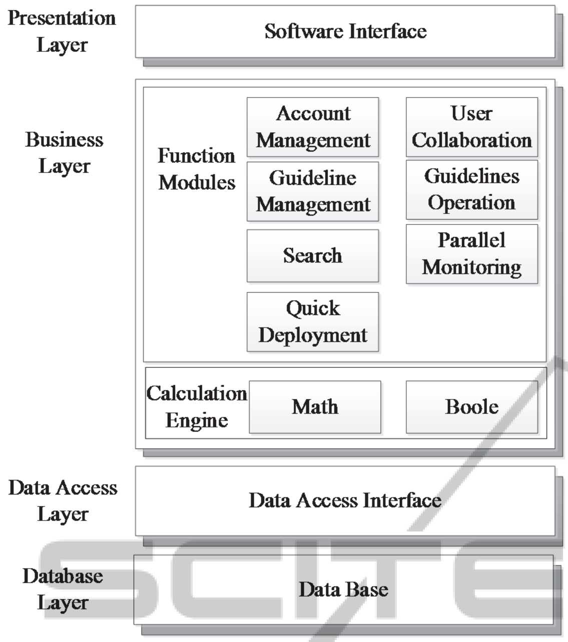

Figure 3: The architecture of CSAMG.

3.3.2 Module Function

The CSAMG could be divided into 7 modules. Each module has relative independent function.

(1) Account Management. This module is used for assigning user roles, and user authorities. There are 5 basic user roles: administrator, operators, TSC technicians, trainer and trainee. Different roles are assigned with different user authorities. The proper role assignment would benefit the user cooperation in the accident. Furthermore, user authority could be assigned separately to qualified users. This is because important operations may have great influence on reactor safety. Only the qualified users could have the right to execute this kind of functions.

(2) User Collaboration. User collaboration is a special feature of AP1000 CSAMG. The cooperation of the 2 major users of AP1000 SAMG, operators and TSC technicians, is the foundation of SAMG implement. So the communication between them would be very important. When they use the paper-based SAMG, the communication is inefficient through talking and writing. In CSAMG, different users could send message to each other in the chat window and also send the link to the present guideline that they are reading. This efficient way of sharing information and opinions is time-saving and helps the users to focus on the issues of accident.

(3) Guidelines Management. CSAMG could automatically evaluate the plant status. If the parameters fulfil the conditions of some guidelines, CSAMG will remind the user to initiate the guideline and follow the instructions. Of course the ultimate power of decision is controlled by the users, they could decide whether to follow the guidelines or not. The content of SAMG needs to be built in CSAMG before usage. The Guidelines management module implement the functions of add guideline, edit guideline, delete guideline and logic builder. Logic builder is used to build the logic that CSAMG need to calculate when it evaluate whether the conditions of guidelines are fulfilled.

(4) Guidelines Operation. Guidelines Operation is the core function of CSAMG. CSAMG display the content of SAMG in flowchart, so the users could clearly know the previous and next steps. The detailed content of present step will be displayed too. Users could mark the present step as an implementing step, and go on to read information of any steps in any guidelines. When the users want to go back to the implementing step, CSAMG provide the return function to go back to the implementing step display interface by clicking one button. It will be very helpful when users need to read a lot of content in many different guidelines. CSAMG also provide the link to the relative operators HMI, where operators need to complete the actions as guidelines instruct.

(5) Parallel Monitoring. CSAMG is connected to the database of plant parameters or severe accident simulator. All the parameters related to the guidelines are monitored in the CSAMG. Any of these that reach the set point or exceed the safe region will cause alarm to users. Users could read the real time value of these parameters, and directly go into the relative display interface of guidelines. For some parameters of particular concern, users could choose them to display on the specific window.

(6) Search. Search function is prepared for the user to find out the specific text information or parameter information, such as which guidelines need to monitor core damage or specific parameters they want to monitor. It contains the fuzzy search function to help user retrieval the information they need. It is useful not only for accident mitigation, but also for the training.

(7) Quick Deployment. Quick deployment means the CSAMG could export the setting of SAMG, so another client could import it to finish deployment.

3.4 Verification and Validation Plan

Since the CSAMG is designed to assist the users to deal with the severe accidents of NPPs, it needs a lot of verification and validation (V&V). The V&V process could be divided into several parts:

(1) V&V of SA simulator;

(2) Verification of CSAMG contents;

(3) Verification of CSAMG logic;

(4) Validation of CSAMG by operating it with the SA simulator.

Firstly the V&V of SA simulator is very important to the whole process of V&V of CSAMG. Because of the uncertainty of severe accidents, V&V of SA simulator itself is a challenge (Jeong, et al., 2002). Our SA simulator will run all the accident scenarios that are analysed in the PSA report of AP1000 NPP. The results will be analysed to make sure it is reasonable.

Secondly the contents of CSAMG must be the same as the handbook of AP1000 SAMG. The CSAMG could export all the contents into a pdf file in the format of AP1000 SAMG. Comparing these two files will verify the contents of CSAMG.

Thirdly the logic of CSAMG needs to be test carefully to make sure that all monitoring parameters and their evaluation mechanism are set correctly.

Last but not least, CSAMG will be operated by connecting to the SA simulator to mitigate the simulated accidents. By the practice, CSAMG could be validated whether it would help the users in the accident mitigation.

4 CONCLUSIONS

In this paper SAMERS is described in brief as an emergency supporting system to deal with the severe accidents. CSAMG, as one of its modules, is an assistant tool for severe accident mitigation. The CSAMG could help the SAMG users to get a better performance.

CSAMG could improve the cooperation between the operators and TSC technicians. It could monitor the plant status automatically and recommend the mitigation strategies. It is efficient to provide useful information of SAMG related to the current accident status. It will save time, reduce human errors, and improve plant safety.

There are some problems in the development of CSAMG. One is the survival of detectors and equipment during the severe accident. The lack of data source could lead to the paralysis of monitoring function of CSAMG. And without the monitoring parameters CSAMG could not evaluate status and provide advices. Another problem is the evaluation of mitigation strategies is based on the current condition and depend on the experience of operators. There are no rules for all the strategies evaluation. CSAMG may provide some improper strategies to confuse the operators. The validation of CSAMG is also a question need further discussion.

ACKNOWLEDGEMENTS

The research is funded by the Chinese National Science and Technology Major Project under contract No. 2013ZX06004-008.

REFERENCES

CNDRC, 2007. *Nuclear Power Medium and Long Term Development Plan (2005~2020),* Beijing: Chinese National Development and Reform Commission.

Gang, C., 2013. *Functional Requirements of Computerized Severe Accident Management Guidelines,* Beijing: SNPSDC.

Jeong, K.-S., Kim, K.-R., Jung, W.-D. & Ha, J.-J., 2002. Development of Severe Accident Management Advisory and Training Simulator (SAMAT). *Annals of Nuclear Energy* , pp. 2055-2069.

Lee, J.-W., Kim, J.-T. & Park, J.-C., 2010. Computer-based Alarm Processing and Presentation Methords in Nuclear Power Plants. *World Academy of Science, Engineering and Technology*, pp. 594-598.

Park, S.-Y. & Ahn, K.-I., 2010. SAMEX: a Severe Accident management Support Expert. *Annals of Nuclear Energy*, pp. 1067-1075.

Robert, F. T., Charles, K. D., Lewis, H. F. & Joseph, N. A., 2009. Guidelines for Design and Implementation of Computerized Procedures. *Nuclear News*, pp. 85-90.

Yuji, N., Hollnagel, E. & Green, M., 1996. Guidelines for Computerized Presentation of Emergency Operating Procedures. *Nuclear Engineering and Design*, 7, pp. 113-127.

Zheng, Y., 2012. The Foundation of Severe Accident Management Guidelines of AP1000 Nuclear Power Plant. *Technology Innovation and Application*, pp. 6-7.