261

# STRATEGY GENERATION IN ACCIDENT MANAGEMENT SUPPORT

Miki Sirola

Technical Research Centre of Finland
P.O.Box 1301, FIN-02044 VTT, Finland

## ABSTRACT

An increased interest for research in the field of Accident Management can be noted. Several international programmes have been started in order to be able to understand the basic physical and chemical phenomena in accident conditions. A feasibility study has shown that it would be possible to design and develop a computerized support system for plant staff in accident situations. To achieve this goal the Halden Project has initiated a research programme on Computerized Accident Management Support (CAMS project). The aim is to utilize the capabilities of computerized tools to support the plant staff during the various accident stages. The system will include identification of the accident state, assessment of the future development of the accident and planning of accident mitigation strategies. A prototype is developed to support operators and the Technical Support Centre in decision making during serious accidents in nuclear power plants.

A rule based system has been built to take care of the strategy generation. This system assists plant personnel in planning control proposals and mitigation strategies from normal operation to severe accident conditions. The idea of a safety objective tree and knowledge from the emergency procedures have been used. Future prediction requires good state identification of the plant status and some knowledge about the history of some critical variables. The information needs to be validated as well. Accurate calculations in simulators and a large database including all important information from the plant will help the strategy planning.

262

# 1 INTRODUCTION

The OECD Halden Reactor Project has noticed an increased interest for research in the field of Accident Management. The NRC in United States has sponsored several programmes for management of severe accidents like extending plant operating procedures into the severe accident regimes and discussion of accident information needs [1]. The Halden Project is putting an effort on this research activity. [2]

A feasibility study has been performed [3], concluding that it would be possible to design and develop a system, meeting the expressed support needs for plant staff in accident situations. In order to achieve this goal the Halden Project has initiated a research programme on computerized accident management support (the CAMS project). The CAMS project was started in 1992. This work aims at utilizing the capabilities of computerized tools to support the plant staff during the various accident stages including:

- identification of the accident state,
- assessment of the future development of the accident,
- planning accident mitigation strategies.

A number of program packages exist to support fault situations and small accidents, but not so many exist for severe accidents. The reasons for this are the difficulties in calculations and the decreasing reliability of simulators when the accidents become more severe. There is no real data available to verify these kind of situations.

A prototype is developed to support operators and the Technical Support Centre in decision making during serious accidents in nuclear power plants. To avoid using a new tool in a stressed situation, CAMS is supposed to help the operators and the TSC in choosing the right control actions or mitigation strategies in small transients as well as in accident cases.

The CAMS proposal consists of a database and a knowledge base, a tracking mode simulator and a predictive simulator, a strategy generator and an MMI system. The CAMS simulators will be built with a dynamic program package APROS. The MMI system will be made with the graphical program package PICASSO-3. The G2 expert system shell is used in the realization of the strategy generator. The strategy generation is the main topic of this paper.

263

The background for the knowledge put into the strategy generator and the existing EOPs is the information got from off-line studies. However, since the development of a severe accident is difficult to predict in advance, the strategy generator will try to adapt mitigation strategies according to the specific accident in progress.

The G2 expert system shell is used in the realization of the strategy generator. G2 is an object-oriented tool for modelling knowledge-based systems including convenient graphical facilities. The strategy generator uses the idea of a safety objective tree and the knowledge from emergency procedures. The prototype is demonstrated on a workstation.

## 2 SAFETY SYSTEMS IN THE NUCLEAR PROCESS

A nuclear power plant, like any thermal power plant, generates electricity through the medium of steam [4]. Part of the energy in the steam is converted to mechanical work in the turbine, which drives the electric generator. About two third of the energy is lost as heat e.g. into the sea water. The steam coming from the turbine is condensed into water in the condenser. This water is pumped via preheaters back into the reactor core (BWR) or back into the steam generators (PWR). The water-steam loop is a closed circuit.

The thermal energy in a nuclear power plant is produced from a nuclear reaction. The energy is generated by the fission of heavy nuclei with neutrons. Most of the energy is released as kinetic energy in the fission products. This kinetic energy is converted into heat on a very short distance by a slowing down process.

It is very important to keep the neutron balance in a fission process. Otherwise an uncontrolled chain reaction may occur. The criticality is measured by neutron detectors. They are checking if the neutron population is increasing or decreasing. The relative deviation from 1 is called reactivity. The correct power distribution is also important. The power in the core is regulated by the position of control rods or varying the concentration of boron in the coolant. Boron is a strong neutron absorber.

It is also important to keep the heat balance. The heat produced in the core ought to be equal to that removed by the coolant so that the fuel temperature keeps constant. Heat conduction in the fuel and the heat transfer to the coolant can be calculated. In a complex system a large amount of stored energy exists. Even if the reactor is shut down, a considerable amount of decay heat is produced.

The reactor protection system in BWR plants is for preventing fuel overheating and for limiting radioactive releases. The three main safety chains are:

- reactor shutdown by hydraulic scram,
- reactor isolation by closure of the reactor containment isolation valves,
- emergency core cooling by actuation of the emergency core cooling systems and the automatic depressurization of the primary circuit.

The pressure relief system is to protect the reactor from overpressure. The condensation system consists of the wetwell of the reactor containment, a nine meters deep condensation pool. The condensation system receives and condenses the discharged steam.

The auxiliary feedwater system is designed to supply the reactor with water if the ordinary feedwater system is unavailable. The low-pressure injection system shall, together with the auxiliary feedwater system and the pressure relief system, protect the reactor core from overheating in the event of a primary system pipe break.

The containment spray system draws water from the condensation pool. The water spray in the drywell contributes to reducing the pressure in the containment by steam condensation. It also removes condensable fission products from the containment atmosphere. During normal operation, cooling is primarily done by the turbine condenser and the main cooling water systems. Part of the heat is removed to the sea. Shutdown cooling system ensures continued cooling via the diesel-backed cooling circuits to the sea during reactor shutdown. [4]

## 3 USING PROCEDURES IN ACCIDENT SCENARIOS

Many kinds of accident scenarios are described. One typical example scenario is a loss of coolant accident (LOCA). A typical LOCA follows a sequence: a leak - inadequate cooling - scram - isolation of the containment - emergency cooling of the reactor. In a LOCA there is a danger of overheated core and in the worst case a meltdown.

The safety objective tree [5][6][7] is a way to systematize different accident cases. Following different branches of the tree, each accident case is specified in more and more detail. On the highest level the safety objective is defined. One level below the objective is divided into several safety functions. This division can be for example according to the four critical functions that are discussed in the context of emergency procedures for BWRs.

The main goal of accident management in BWRs is to maintain the critical safety functions:

- reactivity control
- core cooling
- activity barriers
- heat sink

The priority of these safety functions follows the order of the list. Minimizing the consequences to the environment has higher priority and the electricity production has lower priority than any of the four safety functions. [8]

In the Swedish Forsmark plant they have different procedures for events of varying degrees of severity. The most serious cases are covered by the ÖSI procedures (Emergency procedures) and the THAL procedures (Technical handbook of the plant management). Both these procedures are based on the division into four critical functions.

In the most serious accidents the THAL procedures are used. The ÖSI procedures are used in design-basis accidents and the THAL procedures in beyond-design-basis accidents. [9]

# 4 THE STRATEGY GENERATOR

The knowledge base in the strategy generator is constructed by using the idea of the safety objective tree. The knowledge base includes knowledge from the emergency procedures, e.g. all important parts of the THAL procedures. Also other sources have been used to cover the most important parts in the accident management.

The strategy planning starts from simple rules. If the water level is too high, close slightly a valve etc. From simple control proposals to real accident mitigation strategies a whole scale of different types of advice exist. The strategy planning is a rule-based system making decisions according to the external conditions in the plant. The rules constitute a kind of model of the plant. The strategy planning is the central part of the strategy generator.

The strategy planning consists of goal definition, strategy defin·'on and strategy selection. External communication is needed to exchange information with the database, the predictive simulator and the MMI system. The goals may be general or more specific ones.

```
if not (die1)
and not (die2)
and not (die3)
and not (ex_ene)
then inform the operator that 'Prioritize the
   channel, connect the cabels, give the
   voltage, emergency start of the diesels
   as soon as possible!'
and change the icon-color of core to red
and change the text of the scan-interval of
   thal_cc1 to 'none'
```

```
initially deactivate the subworkspace of
   balance
```

```
if abs (the mass_balance of core) > the
   mass_balance_limit of goal_definition
or abs (the energy_balance of core) > the
   energy_balance_limit of goal_definition
then activate the subworkspace of balance
and change the icon-color of balance to
   orange
```

```
if the level of core < the level_thal_limit of
   strategy_definition
and not (fwi)
and not (efs)
and not (lpis)
and not (bi)
then inform the operator that 'Fill the drywell
   of containment with water!'
and change the icon-color of containment1
   to red
and change the text of the scan-interval of
   thal_hs1 to 'none'
```

```
if the pressure of containment1 > the
   containment_pressure_thal_limit_4 of
   strategy_definition
then inform the operator that 'Activate the
   pressure reduction of containment: start
   the emergency spray system and close
   the isolation valves!'
and change the icon-color of containment1
   to red
and change the text of the scan-interval of
   thal_hs2 to 'none'
```

*Figure 1: Some example rules in the strategy generator*

The goal definition part makes the decisions about which branches of the safety objective tree to follow by activating subsystems in the strategy definition part. Different subsystems are able to handle different types of accidents. Inside these subsystems there are more specified rules providing the first proposals for strategies depending on the external conditions. These subsystems are the heart of the strategy generator.

Some example rules are seen in the Figure 1. The rules on the left hand side are from the goal definition part and the rules on the right hand side strategy definition part of the strategy planning. These rules are taken from the THAL procedures.

In the strategy selection part the data from the predictive simulator is analyzed. For each proposal a quality number is calculated by comparing some important physical quantities to their reference values. A kind of control cost is also taken into account. Some of the reference values changes automatically in a case of scram. Simple optimization methods are used in minimizing the quality number. A procedure is needed in organizing the strategies in a new order according to their quality numbers.

The solution of a simple optimization problem [10] is giving the order. A small quality number is better than a big one. The best strategy is found with the formula

$$minDN=\int_0^T \sum_i P_i (x_{ri}-x_i)^2 dt + \int_0^T \sum_j Q_j (u_{rj}-u_j)^2 dt$$

where

DN = quality number

$P_i$ = weight coefficients for state errors

$(x_{ri}-x_i)$ = state errors

$Q_j$ = weight coefficients for control costs

$(u_{rj} - u_j)$ = control costs

A good estimate of the plant status is essential for strategy planning. A simple simulator exists for state identification. Only the main components of a BWR plant exist in the process diagram. About 40 simple equations take care of the calculations in the core, in the primary circuit and in the containment.

These calculations are based on very simple principles and can be trusted only on a qualitative level. If you open a valve, the water level will increase. In the direction of flow in the primary circuit a pump increases the pressure and a valve decreases it, the preheaters and the core increases the temperature, and the turbine and the condenser decreases it etc. Pressure, temperature and flow are calculated through the primary loop.

History keeping and simple signal validation are applied in the state identification. The availability of measurements, actuators, safety systems etc. is checked and the resources available in the current situation are taken into account in deriving the strategies. It is also possible to check the severity of the problem. All rules defining strategies are divided into three categories according to the priority.

The G2 expert system shell is used in the realization of the strategy generator. G2 is an object-oriented tool for modelling knowledge-based systems including convenient graphical facilities. In the prototype of the strategy generator there are two basic types of elements: process components and calculation elements. The calculation elements are able to handle both numerical calculations and heuristic operations. The prototype is executed on a workstation.

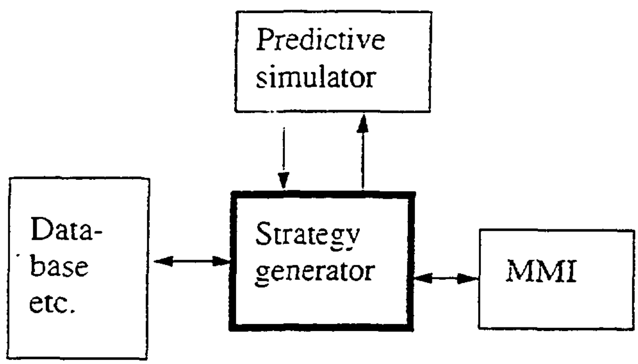


*Figure 2: Communication between the strategy generator and other parts of CAMS*

The communication between the strategy generator and the other parts of CAMS will be based on sending messages between different program packages, see Figure 2.

The prototype of the strategy generator can be tested by running some scenarios. A leak in the primary circuit is a typical small accident case. The prototype is able to give some help and advice. Activity and high pressure in the containment, station blackout, reactivity problems, contradictory information are other examples where the strategy generator can give a helping hand. [11][12]

## 5 CONCLUSION

One purpose of the prototype is to test out different methodologies that can be used in this kind of system. For this purpose the knowledge base is large enough. In a real system much more rules are needed. In the future a larger knowledge base will be made. The aim is to cover different accident cases not necessarily covered directly by the procedures.

The usage of the G2 expert system shell seems to be a good solution. The use of rule-based methods and AI techniques looks promising. More sophisticated ways of using rules could be used. A knowledge base built of logically connected rules is a challenge. Different chaining methods could be used to support more complicated reasoning schemes.

The real test of the capabilities of the system is not possible before all remaining important modules of CAMS exist and work together. The co-operation of the strategy generator and the predictive simulator will be of special interest. It will give the basis for the strategy planning. The possibilities of using the database and knowledge base block, for instance in the state identification, are interesting too. And how to mediate the right figure of a critical situation to the people responsible for the plant? The MMI system is finally an important link in fulfilling this task.

## REFERENCES

[1] Hanson D. J., Arcieri W. C., Ward L.W., Accident information needs, Paper to the Workshop on Computerized Accident Management Support, Idaho, U.S.A. (1992).

[2] Berg Ø., Sirola M., Sørenssen A., Øwre F., Ådlandsvik K. A., The Halden reactor project workshop meeting on computerized accident management support, HWR-335, Halden, Norway (1993).

[3] Øwre F., Porsmyr J., Kautto A., Söderman E., CAMS - computerised

270

accident management support, a feasibility study, HWR-287, Halden, Norway (1991).

[4] Pershagen B., Light water reactor safety, Pergamon press, Studsvik, Sweden (1989).

[5] Arcieri W.C., Hanson D. J., Instrumentation availability during severe accidents for a boiling water reactor with a Mark I containment, NUREG/CR-5444, EGG-2661, Idaho, U.S.A. (1992).

[6] Chien D. N., Hanson D. J., Accident management information needs for a BWR with a MARK I containment, NUREG/CR-5702, EGG-2639, Idaho, U.S.A. (1991).

[7] Hanson D. J., Johnson S. P., Blackman H. S., Stewart M. A., Developing and assessing accident management plans for nuclear power plants, NUREG/CR-6009, EGG-2682, Vol. 2, Idaho, U.S.A. (1992).

[8] Stenmark J-E., Forsmark 2 - övergripande störningsinstruktion for driftvakt (ÖSI), Internal communication (in Swedish).

[9] Stenmark J-E., Teknisk handbok för anleggsledningen (THAL), Internal communication (in Swedish).

[10] Gelb A., Applied optimal estimation, The M.I.T. press, London, England (1974).

[11] Sirola M., The strategy generator in the computerized accident management support system - CAMS, HWR-361, Halden, Norway (1993).

[12] Sirola M., Strategy generator in computerized accident management support system, VTT Publications 163, Espoo, Finland (1994).