AN EXPERT SYSTEM - BASED AID FOR ANALYSIS OF EMERGENCY OPERATING PROCEDURES IN NPPs

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ABSTRACT

Emergency Operating Procedures (EOPs) generally and an accident managment (AM) particulary play a significant part in the safety philosophy of NPPs since many years. A better methodology for development and validation of EOPs is desired. A prototype of an Emergency Operating Procedures Analysis System (EOPAS), which has been developed at GRS, is presented in the paper. The hardware configuration and software organisation of the system is briefly reviewed. The main components of the system such as the knowledge base of an expert system and the engineering simulator are described.

INTRODUCTION

Since many years Emergency Operating Procedures (EOPs) play a significant part in the safety philosophy of NPPs as a further strengthening of the defence in depth principles. Existing conventional event-oriented procedures have been optimized and complemented by symptom-oriented procedures, particularly for beyond design bases conditions. An important step in the development and implementation of EOPs is their validation. For this purpose, different methods based on reviews, walk-throughs or simulations may be used. Concerning simulation methods in real-time, plant specific training simulators are largely used for validation due to their large field of application and effectivity. In practice, for many NPPs, such simulators do not exist or are inaccessible, and/or the existing simulators do not cover the full spectrum of accidents for which the EOPs have to be validated. This makes the application of this method impossible in many cases.

This paper describes a segment of an investigation that was conducted by the Gesellschaft für Anlagen und Reaktorsicherheit (GRS) in the area of EOPs for beyond design base accident to assess and demonstrate the feasibility of using an expert system as an aid for the analysis of EOPs in NPPs. The objective of the effort was to create and evaluate the EOPs knowledge base within the expert system, and to validate some characteristics of EOPs for suitable accident scenarios, simulated with a nuclear plant analyser. A prototype of an Emergency Operating Procedures Analysis System (EOPAS) [Ber96, Jak95] was developed, based on an expert system, and on the nuclear plant analyser ATLAS (ATHLET Analysis Simulator) [Vog93] of GRS.

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GENERAL STRUCTURE OF EOPAS

The EOPAS consist of three main components:

- The expert system containing the EOP’s knowledge base.
- The nuclear plant analyser ATLAS including the simulation code ATHLET and an interactive visualisation system.
- The central data server (Q-server) connected to the expert system and to ATLAS providing data exchange in both directions.

Figure 1 illustrates the relationship between cooperating components of EOPAS. The system runs in the GRS Test Control Room (TCR) facility, which includes the computer architecture, model software, data software and communication system. The main frame, UNIX-workstations (DEC, IBM) and PCs connected in a network represent the hardware of the TCR.

![Figure 1. EOPAS configuration](image)

EXPERT SYSTEM AND EOPs

The EOPs are specific, abstract systems existing in description form or as graphical diagrams. The spectrum of EOPs knowledge is not very large, and is mainly represented by rules. The rule is a method of knowledge representation characterized by an 'If-Then' format. Boolean algebra and fuzzy logic can be used within a rule to store the knowledge in an efficient manner. The expert system with its general structure being composed, the specific knowledge base and inference engine are very well suited for modelling EOPs due their great flexibility.

The expert system shell G2 implemented on a DEC-workstation has been used to describe the EOPs. G2 is an object oriented programm with graphical workspaces [G2-90]. It includes the development tools, such as the interactive text editor, the graphical editor and predefined functions and objects to create the knowledge base and its graphical representation. Structured natural language commands enable the user to create knowledge quickly and easily. The EOPs representation on G2 consist of following functional components:

- a general knowledge base including the basic elements to design the EOPs
- a specific knowledge base including the NPP’s specific EOPs
- a control module which verifies the facts and rules, interprets the user interactions and controls the realization of the procedure.
General knowledge base

Due to the functional similarity of the pieces of knowledge describing the EOPs, it was sufficient to create a limited number of basic elements, in order to cover all facts and relations from which the procedures are constructed. The set can be easily complemented with user defined elements to meet specific application requirements. The basic elements form a library, which consists of the following groups:

- procedure-elements
- logical-gates
- alarms
- interface-elements.

![Figure 2. Procedure-elements](image)

The Figure 2 shows examples of the procedure-elements. The procedures can be represented by only a few basic elements, such as decision-step, advice or action. The functional and graphical properties of the elements allow the creation of a specific knowledge base, and form a graphical surface by interactive object-oriented editing supported by specific G2 tools. The elements can be treated almost as physical objects. They can be cloned, transferred between graphical surfaces, connected to each other (when functional reasons permit) or deleted. The editing gives the possibility to change the sequence of steps in the procedure, pass over the action steps or go through wrong action steps (e.g. for simulating deviations from the normal procedure), without destructing the consistency between graphical representation of a
procedure and its knowledge base. Such changes can be made during the run of the EOPs without interruption of the dynamical data flow from the simulator.

Specific knowledge base

In the specific knowledge base the EOPs knowledge with reference to specific NPPs is stored. In the prototype knowledge bases, the description of the symptom oriented approach and the secondary bleed&feed (B&F) procedure for PWRs have been generated. From functional and knowledge representation reasons the whole specific knowledge can be divided into following groups:

- interface
- procedures
- events
- lead-in criterions.

It is possible to organize each of these groups hierarchically in order to simplify the administration of the knowledge base.

The interface group contains a set of analog values and logical states which are represented by elements from the group of interface-elements. The variables are updated in a defined time interval by the simulator. The elements are described by attributes, such as specific simulator keywords for communication with the simulator, the name of variables in G2, initial values, last recorded values, update interval, history keeping interval.

Two procedures have been created in a specific knowledge base using the procedure-elements, the symptom-oriented approach and the secondary B&F procedure. The symptom-oriented procedures are dedicated to operation at incidents and accidents. They depend on the status of the critical safety functions. This status is regularly scanned by the expert system. The symptom-oriented procedures include accident diagnosis procedures in form of subprocedures, which provide the identification of the reason of the accident for a limited number of scenarios. The secondary B&F procedure is the main procedure in the specific knowledge base. The secondary B&F is a basic procedure for beyond design base accident for German NPPs. The procedure can automatically influence the simulation process ATLAS through action elements. Because of its length (130 procedure steps), the B&F procedure has been divided into three workspaces. The first one is shown in Figure 3.

The status of the critical safety functions and the occurrence of different events is represented by alarm-elements. Their graphical representation (icons) can be different in spite of the same functional description. The critical safety functions play a basic role in the disturbance and accident control since their status allows to decide whether the process is in a safe condition or not. Fuzzy logic has been used in order to show the gradual degree of fulfilment of the safety criteria by colour coding.

A separate lead-in criterion group has been created. This gives the user a better look into the process phase in which the procedure is led-in. The lead-in criterions are represented by connection of logical-gates.

Control module

A control module has been developed that:
synchronizes the data flow from the plant analyzer ATLAS to the expert system
controls the snapshots and the backtrack of the process on G2
switches between automatic and manual mode
initiates, breaks and restores the connection with the data server.

Graphical surface

The procedure diagram, the status of the safety functions and other events are presented on displays in order to give the user fast and extensive information about the procedure which run. The user can require interactive displays from 22 individual graphical workspaces. Different levels of a display hierarchy are possible, ranging from a general view to a detailed presentation. The important events are signalled by intensive colours. The active procedure steps are recognised immediately due to changes of colours. An interactive manual control for running procedures is possible, whereby the user is requested to acknowledge the actions of the system after each procedure step. Figure 3 presents a G2 display, which was used for the analysis of the influence of human errors on the process after a total loss of feedwater supply in a PWR.

![Figure 3. Overview display of EOPs on the expert system screen.](image)

DATA SERVER

The EOPs simulation on an expert system is one of the many processes that run in the TCR. The processes which perform the simulation are usually run on different computers. An
Exchange of information is accomplished by using a central data server (Q-server) [Ber96] with the following features:

- functions as an active interface between different software products
- restores the history of simulation process
- provides fast access to data
- synchronises different sources of data.

The use of the Q-server allows the repetition of simulation runs without rerunning the simulation code.

THE PLANT ANALYZER

Generally, the spectrum of validated EOPs is very large, from event-oriented procedures to accident management (AM). Practically, in the last years the emphasis was placed on the investigation of the symptom oriented procedures and particularly on AM. Therefore, in order to successfully validate the EOPs, the plant analyzer must be able to simulate different accident scenarios including severe accidents.

The GRS plant analyzer ATLAS is designed as an engineering simulator for analysis of reactor transients and accidents, the investigation of EOPs and the validation of diagnosis and control systems. The simulation basis of ATLAS is the thermohydraulic best-estimate code ATHLET. An interface to the containment code RALOC and the integral code MELCOR has been developed. Also, an integration of other simulation codes into the ATLAS software environment is possible.

A significant part of the analyzer is a description of the control, trip and auxiliary systems referred to as Balance of Plant (BOP) systems. The BOP is necessary not only because all plant transients and non-LOCA accidents are initiated by operation or malfunctions within those systems, but also since the response of the plant to transients or accidents is strongly influenced by the automatic operation of the BOP systems.

The simulation code

The system code ATHLET (Analyses of Thermohydraulics of LEaks and Transients) belongs to the group of detailed mechanistic codes. More information about this code is given in [ATH95]. The field of application of ATHLET comprises the whole spectrum of operational and abnormal transients, small and intermediate leaks up to large breaks for BWRs and PWRs including WWER. For the analyses of severe accidents with core degradation, an extended version ATHLET-CD is being developed.

ATHLET includes a dedicated high level simulation language (General Control Simulation Module - GCSM) for the simulation of BOPs. By connecting basic functional blocks (switching elements, logical elements, function generators and other) within the input deck, the user can model the desired control circuit of fluid systems as a block diagram. The process variables can be used as an input to user defined block diagrams. Output signals are for instance rod positions, valve cross sectional areas or boundary conditions for mass or heat addition rate, pressures and temperatures. The connection of external models programmed in FORTRAN is possible through a special interface to ATHLET.
Visualisation

The visualisation system of ATLAS presents graphically the results of the simulation and allows interactively to influence the execution of the simulation process (malfunctions, manual control).

Figure 4. Synopsis for PWR

The system is based on the GKS (Graphical Kernel System) international graphics standard. There are possibilities to manage the displays of the simulator in windows (creating, moving, deleting, printing). A package for trend displays is included in the visualisation system. Different type of displays are available in ATLAS:

- synopses which indicate the general status of the plant
- nodalisation displays generated directly from the simulation codes providing information on the nodalisation of the plant
- subsystem diagrams for showing the subsystem status and for interactive control of malfunctions and manual actions.

Figure 4 shows the synopsis for a German 1300MWe PWR. This display was created to help the user in achieving a greater comprehension of the complicated thermalhydraulic process that occur in the reactor and coolant systems during an accident. Information on the process status is displayed as a two-dimensional dynamic distribution of important parameters along the primary circuit by colour shading and by a set of pictorial elements representing valves, pumps, fluid levels, flow directions by combination of shape and colour.
VALUATION AND CONCLUSION

The influence of human errors on the plant process during execution of the B&F procedure after a total loss of feedwater supply in a PWR 1300 has been studied in order to evaluate the effectiveness of the expert system and to demonstrate the feasibility of the EOPAS [Jak95]. The human errors have been restricted to variations of the delay time between the individual actions of the operator. The results of this study show that the methodology developed within EOPAS has a high degree of potential for evaluating important EOPs characteristics with respect to the plant-specific man-machine communication system. A point of specific interest has been found when considering the technical accuracy of the EOPs instructions. Grammatical terms such as 'rising', 'high', 'low' without further specifications often give rise to misleading interpretations. The transfer of EOPs from the manual to EOPAS has contributed to detect such inaccuracies and to an improved reformulation of the instructions.

In the light of the restricted scope, the limited availability and the high cost of employing plant specific full-scope simulators for procedure assessment, the EOPAS can represent a very convenient and efficient tool for development and validation of EOPs. Further applications of EOPAS are envisaged in training and education, particularly in the AM area.

REFERENCES

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