SUPPORTING THE SAFE OPERATION OF NUCLEAR POWER PLANTS BY THE APPLICATION OF ON-LINE PROCESS INFORMATION SYSTEMS

PhD thesis booklet

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1. ANTECEDENTS OF THE RESEARCH

Development of operator support and process information systems for nuclear power plants is a traditional and successful R&D field in the AEKI (Atomic Energy Research Institute). Formerly the main subjects of our developments were basically determined by the actual needs and operational problems of the Hungarian Paks NPP. However, at the middle of the last decade AEKI initiated the development and installation of such operator support systems, which were already introduced (and successfully used) in Western nuclear power plants, but were missing from the „toolbox" of the operators working at the Paks NPP. The related R&D activities at AEKI were facilitated by that fact that in 1995 the AEKI joined the OECD Halden Reactor Project as an Associated Member. In connection with our HRP membership we had access to the state-of-the-art information related to the development of NPP operator support systems and man-machine interface tools and later we could utilize this know-how in our developments to a great extent. Another favourable condition was that – as part of the so called safety enhancement measures – the Paks NPP had started large scale projects containing (or initiating) the reconstruction of existing computer based systems. The most important projects of this kind were as follows:

- reconstruction of the reactor protection systems (RVR) at all units,
- reconstruction of the plant computer (BSZG) systems at all units,
- development and introduction of symptom-based emergency operating procedures,
- application of a new (radially profiled) fuel type,
- introduction of a new reactor power limitation philosophy.

The above listed projects created a good opportunity to design and install entirely new systems (e.g. plant computer, critical safety functions monitoring) or to modernize existing systems (e.g. core monitoring).

Prior to starting a large scale development activity I always made a comprehensive literature study, where I summarized available publications and reports dealing with the given type of operator support system. I also analyzed the main international trends and studied existing installations. The overview of the related literature is given in the 1st Chapter of the thesis: here I summarize the main characteristics of those operator support systems that can be related to the topics of my thesis. Core surveillance and analysis systems are treated in detail (see [Antila and Kuusisto, 1999]; [Adorján et al., 1985]; [Adorján et al., 1987]; [13]; [16]; [Boyd and Miller, 1996]; [Zalesky et al., 1997]), together with safety parameter displays (see [Manninen and Saastamoinen, 1994]; [Owre et al., 1993]; [Bastien et al., 1993]; [Meslin, 1987]), and plant computers (see [Manninen, 1990]; [Boettcher, 1994]; [Anderson et al., 1994]; [Aleite, 1989]; [Furet and Guesnier, 1995]). Critical safety functions monitoring systems are discussed, as well (see [Owre et al., 1993]; [Bastien et al., 1993]; [Meslin, 1987]; [LO-CSF, 1992] and [Richelle et al., 1994]). In addition to a detailed functional description and illustration of the evolution of these systems I describe some modern systems currently in operation, as well. The Reader thus gets the possibility to compare the merits of these installations with the characteristics of the similar systems developed by us. The treatment focuses on the systems applicable in VVER-440 type reactors.

2. RESEARCH OBJECTIVES

When designing a computerised operator support system to be applied in a nuclear power plant it is essential to define the services of the system properly (i.e. to describe the required functions of the system in various reactor operation states). Information systems monitoring the status of the reactor and the coupled technology can be classified according to the reactor operation states where the system is mainly used by the operators. Generally three basic categories are distinguished in order to characterise the operation state of a reactor, namely: <u>normal</u>, <u>emergency</u> and <u>accident</u> operation states are defined. During normal reactor operation the control room staff routinely uses the basic functions of the plant computer and the core monitoring system. When an emergency situation occurs operators turn to the application of the information originating from the safety parameter display system (SPDS) or from the critical safety functions monitoring system (CSFMS). Generally there is no sharp transition between emergency and accident states, therefore in the early stage of an accident it is sufficient to use the SPD or the CSFM systems only. Later, when the accident develops into a "severe" accident, operators must turn to the application of a special system (if exists) supporting the effective management and mitigation of severe accidents. In most Western nuclear power plants the so called Severe Accident Management Guidance (abbreviated as SAMG) documents were already prepared and introduced (see eg. [WOG-SAMG, 1994]). These procedures are generally paper based (they are used in the form of books), computerised support of SAMG execution is not yet widespread.

The detailed analysis of operators' actions (see the Introduction of the thesis) shows that the control room staff operating and supervising the reactor executes the following four basic actions in <u>all three</u> basic reactor operation states:

- determination of reactor state,
- selection of required actions (strategy or procedure selection),
- execution of selected actions (active intervention),
- checking the result of the actions performed (new state determination).

All the above listed activities can be efficiently supported by suitable computerised systems, but – due to the environment represented by a nuclear power plant – we <u>did not aim</u> to develop computer based systems performing active intervention into the NPP process. However, <u>determination of reactor state</u>, situation dependent <u>selection of operating procedures</u> and <u>checking the new reactor state</u> resulting from the actions performed are such operator tasks that can be efficiently supported by specially tailored computerised support systems.

In my work I concentrated on the development of information systems <u>not</u> performing active process intervention: the task of the systems created is <u>to monitor</u> the observed process and <u>to give advices</u> using well-established process diagnosis. When designing these systems I followed the principle that the operator is the central and most important "actor" in the control of the process. He/she can analyise complex situations and can make proper decisions, provided that he/she is served with reliable information in a comprehensive manner. The most important function of the operator support

systems developed by us is exactly the synthesis and the user-friendly display of the information required to make correct decisions.

The convenient and "user-friendly" information presentation is a key issue when dealing with information systems handling a large amount of measured and calculated data. Therefore in all our development projects it was a very important objective to create a user interface that ensures easy and clear overview of the monitored process, generates quick and unambiguous alarms when potentially dangerous situations are detected. In addition, the handling of the user interface should be very simple, in order to ensure that operators can use it properly even in those complex emergency situations which represent a very high mental and cognitive load on the control room staff.

Our additional development objective was to gradually extend the application area of our operator support systems from normal operating states to emergency and potential accident states. First – parallel with the commissioning of the Paks NPP units – we concentrated on systems applicable during normal operating states, this work resulted the VERONA core monitoring system. The basic functions of the recently upgraded plant computer (BSZG) belong to the same category, but this computer configuration also contains a Critical Safety Functions Monitoring system (developed by AEKI), supporting the operators during emergencies.

The need to create an information system working also in accident states first emerged in connection with the establishment of the CERTA nuclear crisis centre, developed for the Hungarian Nuclear Safety Directorate. Now the centre hosts a safety parameter display system (developed by AEKI), supporting the work of the NSD experts during potential accidents at Paks NPP by on-line data transfer and information display.

The development and introduction of the severe accident management procedures (SAMG) for the Paks NPP is expected in the coming years. In connection with this project it is very likely that a computerised system to support SAMG execution will be developed, as well. When having this system ready the reactor operating states covered by our operator support systems will be complete: from the normal states to the severe accident states we shall have a suitable support system to help the operators' work.

3. RESEARCH METHODS

Development of process information and operator support systems is a rather complex, multidisciplinary activity: in order to create a reliable system which is trusted by its users one must possess a fairly deep knowledge of the process to be monitored, must have an expert developer's level in handling the computer technology to be applied (i.e. hardware, network, software), and must master on-line programming techniques. The design of a proper human-machine interface requires the knowledge of the various activities carried out by the control room staff, a detailed analysis of ergonomic and functional requirements, and the programming tools applicaple for the creation of an optimal user interface.

The design phase is probably the most important period during the creation process of a computerised operator support system. In principle the design phase consists of three

basic activities: in the first phase tasks of the new system must be determined. System functions during various reactor operation states must be defined, together with the scope and access methods of relevant process measurements. The scope of calculated signals (i.e. variables derived from input measurements) must be determined and the requirements for the user interface must be clearly outlined. In this phase important system parameters are quantified, as well: e.g. measurement cycle time, maximum data flux, expected display update time, reliability and availability requirements, maximum size of the process database, etc. In the preparation of specifications the potential users of the new system play a very important role, their involvement is indispensable. The result of this work is the <u>Functional Specification</u> of the new system, which later serves as the basic document for detailed system design. The next milestone in the design process is the creation of the <u>Conceptual Plan</u> (i.e. feasibility study). In this document the development team outlines its proposals to fulfil the requirements given in the Functional Specification: e.g. what kind of hardware architecture and software tools should be used, what kind of algorithms (models) should be applied. The preparation of a Conceptual Plan is generally preceded by a complex analysis, the most important questions to be analysed are as follows:

- <u>Analysis of measurements corresponding to the process to be monitored</u>

    Characteristic process parameters must be carefully selected and the corresponding <u>measurement points</u> must be identified in the technology. Proper functioning of the selected measurements must be clarified in those reactor operation states, where the planned system is to be used by the personnel (e.g. identification of those parameter ranges which are <u>not covered</u> by the available measurements, analysis of transducer behaviour in extreme temperature, pressure and radiation conditions, availability of redundant sensors). The result of this analysis determines a minimum measured input signal set, which is required and sufficient to fulfil all system tasks.

- <u>Analysis of calculations required for process monitoring</u>

    In this procedure those algorithms are defined which are necessary to determine all calculated signals required for process monitoring (e.g. non-measurable in-core parameters). The selected algorithms must fulfil the <u>accuracy</u> requirements given in the Functional Specification document, as well. Obviously this analysis may lead to a conclusion that a significant model improvement is required in order to achieve the prescribed accuracy targets.

- <u>Analysis of fulfilment of quantitative requirements</u>

    It must be outlined how reliability, availability and data processing (e.g. speed) requirements (detailed in the Functional Specification) will be satisfied by the new system: e.g. what kind of hardware and network architecture will be applied, what kind of operating system and application software will be used, etc. In case of important systems, where continuous, uninterrupted operation is expected one must also define solutions applicable to avoid potential data losses or to perform automatic reconfiguration procedures of system resources (e.g. continuous self-diagnostics and peformance supervision). Distribution of redundant measurements

to independent data acquisition units must be analysed and a suitable reservation strategy for the network communication routes should be worked out. This analysis finally results practical information for the <u>sizing</u> of the new system: based on this information experts can design server and workstation resources (e.g. processor speed, memory size, disk capacity, etc.), as well as the necessary bandwidth and redundancy of network communication devices. Generally this analysis requires a lot of experiments (assessment and testing of hardware devices and software tools), it may even happen that some application software modules must be programmed in their final form in order to carry out more or less realistic tests.

- <u>Analysis of human-machine interface functions and outlay</u>

  Generally the design of a new man-machine interface begins with the establishment of a so called <u>user model</u>. This model identifies potential system users and their tasks, determines what kind of user interface elements are used by them during their routine work. A well-established user model facilitates the creation of a proper authorisation system and the adjustment of HMI services to special user needs. This analysis supplies information for the detailed design of HMI tools, display formats and functions dedicated to serve special user groups. The information used for the creation of a user model generally originates from the evaluation of questionnaires and from personal interviews with the future users of the new system. Results from local inspections and walk-arounds are utilised, as well.

In the final phase of the design process the <u>System Design Document</u> is issued. This document outlines the proposals of the Conceptual Plan is such a detailed manner that it can form the base of programming of the whole operator support system. In case of information systems to be installed at the NPP the System Design Document is the main document in the licensing procedure, therefore descriptions must be accurate and deep enough, in order to minimise changes during the realization process. In these cases the System Design Document is complemented by a <u>safety analysis</u>. It describes safety functions realized by the new system and analyses the effects of potential system failures or degradations on the safe operation of the reactor unit.

The desing process of all operator support systems treated in the thesis followed the above outlined multistep procedure.

In the first part of the <u>realization phase</u> all functional modules are programmed according to the contents of the System Design Document. The applicable software development environment depends on the tasks to be solved, as well as on the selected platform and operating system. <u>Fortran</u> is the traditional "language" applied for coding algorithms (e.g. thermal-hydraulic, reactor physical calculations), recently interactive, „Visual" Fortran versions are also available on the market. Parallel with the expansion of PC-based software development tools the application of <u>Visual C</u> and <u>C++</u> languages becomes more and more widespread. These tools were originally applied mainly for PC user interface programming, but gradually they became dominant in other application areas (e.g. creation of network communication programs), as well.

For a very long time the X Windows/Motif graphic standard (and the associated software development environment) was the only applicable tool under VMS and Unix operating systems if programming of user interfaces was considered. The X Windows represents a robust client-server model, generating low network traffic, but it is being gradually ousted due to the rapid development of the PC-based graphics. Presently the Windows GUI (Graphical User Interface) is a widely used and very efficient tool for developing user interfaces, ensuring a highly competitive price/performance ratio. This leading role is not influenced even by the following disadvantage: the network traffic required for information display was increased dramatically, because process data must be transferred to the PC through the network (in the X client-server model only graphic commands are sent through the network, process data are handled in the mainframe). Increased network traffic was compensated by dramatic developments in the network hardware and software components: high-speed 100 Mbps networks are routinely used in industrial applications by now. The DECnet network transfer protocol (which was earlier very popular due to its reliability and transparent programming features) was everywhere replaced by TCP/IP (this protocol became practically dominant due to the Internet). The rapid development of Internet technology initiated important changes in document (i.e. textual information) handling: the application of HTML documents viewable in a standard hypertext browser (e.g. MS Internet Explorer) for electronic handling and visualization of industrial systems' operational documents represents a real breakthrough. The perspectives of these changes are not predictable today: e.g. the complete omission of paper based procedures is a valid option in the near future. Java, the language supporting the animated display of HTML pages is spreading rapidly due to the fact that it can be used for the creation of platform-independent applications.

Finally a brand new approach must be mentioned, as well: this is the use of Scada (Supervisory Control And Data Acquisition) systems, which are spreading in industrial applications. In principle a Scada is a general-purpose software shell, which contains the most common industrial data acquisition interfaces, the basic data processing and display functions and a simple database. By using such a system plant experts are able to create small-scale data acquisition or process monitoring systems, without being experts in programming. Its definite advantage is the efficient creation of applications, on the other hand it has some drawbacks: generally the shells are quite "closed", i.e. the implementation of new or special functions is not an easy task. In spite of these problems the number of industrial Scada applications is growing rapidly, mainly due to their standardized features.

Our operator support systems run under VAX/VMS, OpenVMS or Win-NT operating systems, they were developed mainly in Fortran and in C/C++ (Microsoft and Borland versions). For a long time we used X Windows based graphics but then we also turned to the gradual application of Windows GUI. Programs dealing with network data transfer exclusively use TCP/IP protocol. The HTML standard is used for handling of electronic documentation, the associated programs are written in Java (Sun). The iFIX Scada system by Intellution is the basic software shell of the new plant computer at Paks NPP and – partly – it was used in our Critical Safety Functions Monitoring system, as well.

The next part of the realization phase contains validation and verification (V&V) tests, when programs are tested at module level and integrally. In case of operator support systems the most important test procedure is the integral test, therefore I will discuss applicable methods in detail. In order to perform a comprehensive test for an operator support system it is essential to supply consistent technological data corresponding to all reactor operation states "covered" by the information system. The best tool to create such consistent data is the Paks NPP full-scope simulator, therefore the simulator was extensively used for the qualification of most systems treated in this thesis. During the V&V tests the new system (or its functional equivalent) was installed at the simulator, but measured signals coming from the plant's data acquisition units were replaced by appropriate simulated signals. These "measured" signals are collected by special programs running in the simulator computer and then transferred through the network to the information system. Here the signal processing takes place exactly in the same manner as in the configuration running at the plant. In order to test various functions of an operator support system, appropriate simulated scenarios (so called transients) were designed in co-operation with the simulator instructors. Then these transients were executed during a simulator training session, where operators used the human-machine interface of the new system to retrieve and display process information. During the sessions observers registered operator's actions, the functioning of the new system, and analysed the correctness and consistency of the information displayed. We made interviews with the operators after several sessions: they filled in questionnaires inquiring usability, ergonomy and weak points of the system under investigation. The experience obtained during the tests was then analysed and errors detected in the man-machine interface and algorithms were duly corrected. Active involvement of future system users into the V&V tests produced very positive results: the final system (installed at the plant) was already free from disturbing errors and awkward interface behaviour, it was functioning in a manner fully accepted by the operators. The above outlined method was fully applied for the Paks CSFM system: the first test (aimed primarily to check the correctness of algorithms) was performed in parallel with the simulator validation of the new symptom-based emergency operating procedures. This was later followed by a second test session, which mainly focused on the testing of the human-machine interface.

A different but rather frequently used test method is the so called parallel operation, and the remote data feeding (the latter was introduced by me). In the first case the full plant configuration of a new information system is installed at its final operation site. All measured data are fed into the new system, as well, parallel to the old one which serves control room staff with process information in a fully undisturbed manner. During the parallel operation those quantities, which are determined in both systems can be compared conveniently and tests with real data acquisition units can be performed in the real plant environment. The drawback of this test method is that the parallel feeding of two systems from the same data acquisition unit sometimes can be achieved only by rather expensive modifications (sometimes it is even impossible).

This drawback is eliminated by the remote data feeding method, when measured data are taken not from the data acquisition units, but from the data processing computers

and then transferred to a „remote" configuration through the network. The hardware and software of this remote configuration is the <u>same</u> as for the plant configuration, but it does not contain data acquisition units. Generally this method is applied to perform comprehensive tests of software modifications carried out in already existing systems. In these tests the results given by the original (i.e. licensed) and the modified software can be compared very well and the new software can be thoroughly qualified. Parallel operation was successfully used to carry out commissioning tests of the VERONA core monitoring system and the new Paks plant computer. Remote data feeding is a proven tool to check VERONA software modifications, the method was accepted by the nuclear safety authority, as well.

Finally the application of <u>artificial signals</u> must be mentioned, this test method is quite frequently used in Factory Acceptance Test procedures. These signals are generated by appropriate, so called stimulator programs: these programs can simulate the behaviour of the data acquisition units, but they can produce extremely high data fluxes, as well. This method is mainly used to create very high loads on the input side, when the systems' response to the maximum specified data flux can be investigated (e.g. proper functioning of data communication, no data loss in the archives, delays in information display, etc.). This method was frequently used to test the new plant computer under extreme load conditions.

The final stage of the realization phase is the installation (mounting), site acceptance tests, commissioning tests and the preparation of system documentation for the users and developers (programmers). Tests performed during the installation phase generally use a combination of the above outlined test methods, usually they are based on the <u>V&V Plan</u> prepared for the Factory Acceptance Test. <u>Acceptance criteria</u> are defined by using requirements given in the Functional Specification and the System Design.

In principle an operator support system can be considered as a large sofware system, therefore its <u>life cycle</u> is not over when it is installed and successfully commissioned. However, in the further stages of the software life cycle mainly such methods and activities are required which are beyond the scope of the present thesis (e.g. software configuration management, tracing of software modifications).

4. NEW SCIENTIFIC ACHIEVEMENTS AND PRACTICAL APPLICATIONS

1) In the first version of the Paks NPP VERONA core monitoring system I have designed and prepared the on-line program modules calculating primary circuit coolant flows, primary and secondary side thermal powers from measurements available in the technology.

When starting up the units of the Paks nuclear power plant an important condition for the safe operation of the VVER-440 type reactors was the installation of an on-line core monitoring system, which was able to supply continuous and reliable information to the operators on the actual core state, and could calculate distances of the important core parameters from their safety limits. The AEKI has played an initiating and leading role in the creation of such a core surveillance system: together with my colleauges I

participated in the design and implementation of the first version of the VERONA system. I have designed and elaborated the on-line algorithms for reactor, primary loop and steam generator power calculations, as well as the program modul performing primary coolant flow determination (in principle these algorithms are still running in the present VERONA version). In addition, I have designed and programmed several important other modules (e.g. determination of long term integrals, "accumulation" of process parameters). Further details are given in Chapter **2.1.** of the thesis, algorithms are listed in Appendix **F2.**

2) In the EMERIS on-line information system (developed for the MR materials testing reactor of the Kurchatov Institute) I have designed and implemented the modules calculating neutron physical and thermal-hydraulical parameters of the reactor and the experimental loops.

In the framework of a large-scale project KFKI AEKI has developed and installed the EMERIS (**eMeR I**nformation **S**ystem) on-line information system performing the real-time supervision of the MR materials testing reactor and its experimental loops (the MR was operated by the Kurchatov Atomic Energy Research Institute, Moscow). The main task of the information system was to support the operators of the complicated reactor system by the following services: (1) collection of process measurements from the data acquisition units through the network and standard processing of measured signals; (2) periodic reactor physical and thermal-hydraulical calculations in order to ensure the continuous analysis of the core and the experimental loops; (3) generation of events and alarms, storage of measured and calculated signals in the periodic and change-sensitive archives; (4) automatic identification and diagnosis of disturbances occurring in the technology; (5) concise displaying of process information. I have participated in the design and installation process of the EMERIS: I have designed and implemented the algorithms for the calculation of neutron physical and thermal-hydraulical parameters of the core and the experimental loops (e.g. calculation of power, axial temperature distribution of the coolant and fuel cladding, steam content at fuel assembly outlet, boiling-crisis analysis, burnup determination, xenon poisoning, reactivity parameters, long time integrals). I have also designed and programmed other important modules (e.g. modules performing data archivation). Further details are given in Chapter **2.2.**, algorithms are listed in Appendix **F3.** (Ref.: [17] and [18]).

Considering its reactor physical and computer technological features, the information system is an outstanding engineering product. Remarkable solutions were incorporated to ensure almost 100% system availability by automatic resource reconfiguration, to handle the object-oriented database and to implement fully data-driven calculations.

3) I have initiated the elaboration of a prototype expert system for the on-line analysis of the Paks NPP and headed the related R&D work at AEKI. I have created an object-oriented representation of the VVER-440 technology, then I have designed and implemented the user interface of the expert system.

In the middle of the last decade – due to the rapid development of computer technology – some high-performance expert system shells could also be applied for on-line

monitoring of nuclear power plant processes. Based on international experience I have initiated the application of the G2 expert system shell (Gensym, USA) for the creation of a prototype integrated NPP information system to be used at the Paks power plant. Later I headed the joint R&D work performed by KFKI AEKI and MTA SZTAKI, the project was supported by the OMFB, as well. In the development process I have designed the architecture of the prototype system and elaborated an object-oriented representation of the technology characterizing VVER-440 type NPP units. I have elaborated the method for feeding the system with simulated data and programmed the corresponding interface modul. I have also elaborated principles and procedures of system validation and testing by using a simulator. I have designed and implemented the human-machine interface of the prototype system, together with the tools for alarm and event displaying. Details are outlined in Chapter **4.1.** (Ref.: [12], [15] and [21]).

The GPCS (**G**2-based **P**lant **C**omputer **S**ubsystem) on-line, real-time prototype NPP information system integrates a large number of signals from various data acquisition units. It is able to perform intelligent process monitoring and it can handle procedural and rule-based knowledge simultaneously. The GPCS prototype system and the applied development method could be considered as a novel approach in Hungary.

4) I have designed and implemented the operators' interface for the upgraded and extended version of the Paks NPP VERONA core monitoring system and developed several other important functional modules.

The general reconstruction of the Paks NPP VERONA-plus core monitoring system (developed by KFKI AEKI) was finished in 1998, resulting the thoroughly upraded and extended VERONA-u system. During the reconstruction project I played a leading role in the conceptual planning, design, as well as in the programming, testing and installation work. I have designed and implemented the modern human-machine interface of the new system. In addition, I have designed and developed several important program modules: interfacing the reactor physics calculations, determination of long term integrals, data feeding from the simulator. Recently I play a similar role in the R&D projects aimed at the design and implementation of further VERONA functional upgrades. Details are given in Chapters **2.3**, **2.4** and **2.5**, while Appendix **F4.** shows the components of the user interface (Ref.: [1], [4], [13], [16] and [22]).

Considering its reactor physical and computer technological features, the VERONA core monitoring system is an outstanding engineering product. Now the system is in full operation at all units (and at the full-scope simulator) of the Paks NPP: in the past years it was successfully supporting the safe operation of the plant.

5) I have initiated the elaboration of a prototype information system for on-line monitoring of critical safety parameters at the Paks NPP VVER-440 reactors and headed the related R&D work of AEKI. I have designed and implemented the human-machine interface of the system and developed the visualization principles applicable for displaying emergency operating procedures.

The development work – supported by OMFB – resulted a prototype operator support system applicable for on-line evaluation and display of critical safety parameters in VVER-440 type reactors. During the design and implementation of the CRISP (**Cri**tical **S**afety **P**arameters) prototype system I have analysed critical (i.e. vital) safety functions applicable in VVER-440 reactors and determined technological parameters required for monitoring the state of these safety functions. I have elaborated prototype critical safety function (CSF) status trees and developed appropriate methods for the on-line evaluation and display of the status trees. In connection with CSF status monitoring I have designed a prototype software modul for computerised handling of emergency operating procedures (EOPs). The modul is able to follow the execution of the EOPs and it automatically displays technological information referred in the steps. During the development of this prototype system I have obtained valuable experience that I could very well use for the design and implementation of a similar system developed for the Paks NPP. Besides heading the related R&D work I have designed and implemented several important programs: e.g. software modules performing on-line evaluation and display of reactor safety status. Details are given in Chapter **4.2.** (Ref.: [11], [12], [19] and [20]).

6) I headed the development work aimed to establish the CERTA VITA on-line safety parameter display system for the HAEA NSD and I played a leading role in the design and implementation process. I have developed the human-machine interface of the system and the software modules performing on-line evaluation of reactor safety status and the categorisation of potential accident states.

In 1996 the Nuclear Safety Directorate of the Hungarian Atomic Energy Authority (HAEA NSD) launched a large scale project to establish CERTA, a modern nuclear emergency response and training center (Centre for Emergency Response, Training and Analysis). An important part of the crisis centre is represented by the VITA (Vital Information Transfer & Analysis) on-line information system, developed and installed by AEKI. The basic task of VITA is to perform on-line monitoring of the four Paks NPP units and to support the experts of the NSD by providing the following services: (1) maintaining an on-line data link with the technological computer system of the plant; (2) standard processing and storing of measured plant data; (3) displaying a safety parameter screen together with pictures, trends and p-T diagrams; (4) automatic categorisation of accident states; (5) estimation of reactor pressure vessel water level and calculation of other break parameters in case of loss-of-coolant accidents; (6) transfer of on-line and archived plant data to accident diagnosis and prognosis codes running on various CERTA computers; (7) playback of transient scenarios recorded at the Paks full-scope simulator for training purposes.

In addition to heading the development work and designing the VITA system, I played a leading role in its programming, testing and installation, as well. My most important task was to implement the safety parameter display and the graphic user interface, but I programmed some other important software modules (e.g. evaluation of reactor safety status, analysis of technological subsystem states, categorisation of accident states, data communication programs, data interfaces to accident diagnosis and prognosis

codes). Details are given in Chapter **3.**, while Appendix **F5.** shows the components of the safety parameter display screen (Ref.: [5], [10], [11] and [20]).

Now the VITA is in continuous operation at the CERTA crisis centre making the on-line authority supervision of all Paks NPP units possible.

Considering its services and computer technological features, the VITA system is an outstanding engineering product. Novel solutions were applied for the utilization of the training simulator, for feeding accident prognosis codes with plant data, as well as for the implementation of data-driven calculations.

7) I have initiated and headed the development of a Critical Safety Functions Monitoring system for the Paks nuclear power plant. I have designed the human-machine interface of the system, developed the modules performing reactor safety status monitoring and elaborated modern visualization principles for displaying symptom-based emergency operating procedures.

The Paks NPP started the modernization of its outdated plant computers in 1998: in the reconstruction process state-of-the-art, high-capacity plant computer systems were installed on all units, parallel with the upgrading of the reactor protection systems. The increased computing resources and the available modern programming tools made it possible that new functional modules and operator support tools could be incorporated into the upgraded plant computer, in order to enhance safe plant operation. The first of these modules is the Critical Safety Functions Monitoring (CSFM) system, developed by KFKI AEKI in close co-operation with NPP experts. The system supports the work of the operators by providing the following services: (1) evaluation and visualization of CSF status trees showing critical safety function states; (2) continuous evaluation and displaying of the safety status of the reactor and the most important technological subsystems; (3) computerised handling (i.e. controlled browsing) of symptom-based emergency operating procedures and automatic displaying of process information used in the procedure steps. The development of the new information system was supported by an international co-operation: the work was partly carried out in an OECD/NEA project called PLASMA (Plant Safety Assessment and Monitoring). The research institute IFE Halden (OECD Halden Reactor Project, Norway) participated in this project, as well. I have acted as AEKI representative in the management of the project, and worked as scientific leader during the design and installation of the new operator support system. In addition to designing the system's architecture and functions I have played a leading role in the simulator validation and in the site installation work. My main task was to elaborate algorithms for reactor safety status monitoring and to perform their simulator validation, including development of test procedures and test evaluation methodology. I have designed the human-machine interface of the system and modern methods for the HTML-based visualizaton of symptom-based emergency operating procedures, together with the principles for "embedding" the procedures into the technological process. Further details are given in Chapters **4.3**, **4.4** and **4.5**, while Appendix **F6.** shows components of the user interface (Ref.: [2], [3], [6], [7], [8], [9]).

The CSFM system is a state-of-the-art engineering product if its services and the applied computer technology is considered. Remarkable solutions were applied for the computerised visualization of symptom-based procedures, for information integration and for the utilization of modern programming tools. The new system forms an integral part of the new plant computer and now runs at all units of the Paks NPP (plus at the full-scope simulator). The CSFMS is in pilot operation, its declaration as an official plant system is expected in 2003, parallel with the introduction of the new emergency operating procedures.

The majority of the above outlined research belongs to R&D work supporting the safe operation of nuclear power plants. A large part of the achievements can be directly connected to the solution of various safety problems at the Paks NPP or to the enhancement of the plant's operational safety. As a consequence, research results were mainly communicated in conference proceedings, reports, research papers, as well as in documents prepared for IAEA or OECD NEA specialists' meetings and in research reports prepared for domestic and international organisations.

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