Analysis of Paks NPP Personnel Activity during Safety Related Event Sequences

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Abstract

Within the AGNES Project (Advanced Generic and New Evaluation of Safety) the Level-1 PSA model of the Paks NPP Unit 3 was developed in form of a detailed event tree/fault tree structure (53 initiating events, 580 event sequences, 6300 basic events are involved). This model gives a good basis for quantitative evaluation of potential consequences of actually occurred safety-related events, i.e. for precursor event studies.
To make these studies possible and efficient, the current qualitative event analysis practice should be reviewed and a new additional quantitative analysis procedure and system should be developed and applied.

The present paper gives an overview of the method outlined for both qualitative and quantitative analyses of the operator crew activity during off-normal situations.
First, the operator performance experienced during past operational events is discussed. Sources of raw information, the qualitative evaluation process, the follow-up actions, as well as the documentation requirements are described.
Second, the general concept of the proposed precursor event analysis is described. Types of modeled interactions and the considered performance influences are presented. The quantification of the potential consequences of the identified precursor events is based on the task-oriented, Level-1 PSA model of the plant unit.

A precursor analysis system covering the evaluation of operator activities is now under development. Preliminary results gained during a case study evaluation of a past historical event are presented.

INTRODUCTION

Operational events have been evaluated qualitatively since the first unit was put into operation at Paks. Criteria for the events being evaluated or even reported to the authority underwent several modifications. Some events evaluated in the past are found to be not significant nowadays, thus they are not reported or even not evaluated at all. Since the completion of the Level-1 PSA study within the AGNES safety re-evaluation project an issue has been raised of the possibility of evaluating the operational events quantitatively, determining the risk significance of the real occurrence and drawing conclusions based on its impact on safety.

Evaluation of the human performance in an operational event has always formed an integral part of the qualitative evaluation process. At the same time, outstanding efforts have been made in the field of human reliability analyses within the framework of the Level-1 PSA in order to be able to quantify probabilities of human errors. This has led to the conclusion that the methods developed and used for HRA purposes in the Level-1 PSA could be adopted also for the assessment of human performance in the process of quantitative evaluation of operational events.

The qualitative evaluation process is performed mainly at the plant by plant personnel. The evaluation process is briefly described in the first part of the paper. Activities on quantitative evaluation of operational events have been initiated by the Hungarian Atomic Energy Authority. The proposed concept of the evaluation process as well as tasks carried out up to date are described in the second part of the paper.

1. QUALITATIVE EVALUATION OF HUMAN PERFORMANCE

Paks NPP operates 4 VVER V-213 type reactors. The NPP has a successful operational history. The units were put into operation in 1983, 1984, 1986 and 1987 respectively. Since then 169.962 GWh electricity was generated up to 1996, with a very good rate of availability. The plant has performed above the international average for many years as it can be seen on the capacity factor in the table below.

	Capacity Factor				
	1992	1993	1994	1995	1996
World median	77.6	80.1	81.1	81.4	82.8
Paks NPP	87.2	87.3	89.7	88.6	91.0

From start of the commercial operation of the first unit 52 automatic reactor trips have occurred altogether with the following distribution:

Scrams/unit	1982	1984	1985	1986	1987	1988	1989
Scrams/unit	0.75	1.51	1.52	1.93	0.24	1.25	0.26

1.1. Human Performance in Operational Events

For the four units 732 events have been investigated on corporate level. All these events are classified on the INES scale and show increase in number, but decrease in severity. In the year 1996 71 safety related events occurred and were investigated. It can be established pursuant to the monthly distribution of events given in the table below that the decisive majority of events occurred in the maintenance period - between April and October - characterizing the impacts of the high flux of events typical to this period.

Month	Number of Events	Unit outages
January	4	
February	2	
March	1	
April	7	Unit 4
May	8	Start of Unit 1
June	9	End of Unit 1, Start of Unit 3
July	9	End of Unit 3
August	9	Start of Unit 2
September	2	
October	9	End of Unit 2
November	2	
December	9	

Certain conclusions can be drawn from the above figures (not supported fully by statistical data) concerning the correlation between overhaul and the number of events occurring. In the periods of overhaul, a relatively higher number of events have taken place on the units concerned. During this period, some increase in the number of events can be observed on the twin-unit as well. Continuing the investigation of these events, the following distribution of causes leading to the occurrence of the events can be observed:

equipment related	-	60 %
personnel related	-	32 %
procedure related	-	7 %
others	-	1 %

In compliance with previous years, equipment failures occur the most frequently followed by human errors. Performing a more detailed investigation of equipment failures, the following distribution among the fields has been found:

mechanical	-	26 %
I&C	-	14 %
electrical	-	60 %

The breakdown indicated above shows the frequent failure of electrical systems. Performing a more detailed investigation similarly for the human related causes of the events the following distribution of errors among the personnel has been obtained:

operating	-	52 %
maintenance	-	26 %
planning	-	9 %
auxiliary	-	9 %
commissioning	-	4 %

Similarly to previous years of operation the number of errors committed by the operational staff appeared to be the most significant among the human errors. The number of *documentation errors* was relatively small (5), they have the following distribution among the different kinds of documentation:

operating procedures	-	40 %
maintenance procedures	-	20 %
program	-	20 %
design	-	20 %

Concerning the effectiveness of prevention it can be established that nearly one third of deviations had been detected and/or occurred in the course of scheduled or non-scheduled tests and programs. Deviations detected in the course of operation and maintenance represent a similar distribution as given below:

planned test	-	21 %
unplanned test	-	13 %
operation	-	31 %
maintenance	-	35 %

1.2. Safety Related Event Investigation and Feedback

In case of the occurrence of a safety related event the personnel on duty have to write a report by filling out the regular event report form. In case of events extending over several shifts the reports have to cover the period between two changes of shifts or the whole period of time until the normal operational state restored. All documents including the readings, computer data archive related to the event have to be attached to the written reports.

Safety related events or incidents fulfilling the reporting criteria are to be reported verbally and also in written to the Nuclear Safety Directorate of the Hungarian Atomic Energy Authority with its rating determined according to the INES manual.

Investigation

An investigation revealing the direct cause of the incident or safety related event has to be started after the stabilisation of parameters under direction of the shift supervisor. The on-call safety engineer of the Safety Division has to arrive at the plant in the shortest possible time and join the investigation. An in-depth investigation of the event is led by the safety engineer of the Safety Department. The organisations concerned in the given incident or safety related event are obliged to support the investigation in every respect.

In order to make the circumstances of the event clear and yield as many insights as possible the person conducting the investigation makes inquiries among the personnel concerned directly or indirectly with the event. During the investigation the root cause of the event is to be analysed in order to reduce frequency of occurrence of the given event in the future.

The final report is sent by the Section of Operational Safety to the Safety Manager for approval. The Safety Manager confirms the conclusions and the actions to be taken as a result of the event investigation. The detailed report of the event prepared on the basis of the investigation report has to be sent to the Nuclear Safety Directorate in 30 days after the event.

Feedback

The Safety Division is responsible for tracking the action plans, preparing training material and conducting the training of the lessons learned to the personnel. In order to enhance the availability and operational safety a summary is prepared about the reports of event investigations for the quarterly and yearly meetings of the Operating Review Committee, which surveys the performance of the actions ordered during the investigation of events

2. QUANTITATIVE EVALUATION OF HUMAN PERFORMANCE

Within the AGNES Project the Level-1 PSA model of the Paks NPP Unit 3 was developed in form of a very detailed event tree/fault tree structure. This model gives a good basis for quantitative evaluation of potential consequences of actually occurred safety-related events, i.e. for precursor event studies. Such activities were initiated by the Hungarian Atomic Energy Authority in 1995 and the VEIKI Institute for Electric Power Research Co. was charged with developing methods and tools to be able to carry out those kinds of evaluations. VEIKI has made a proposal for a "precursor program" and a number of steps have already been taken in building up its framework. Following is a brief description of the proposed precursor program, the tasks performed so far, some details about the approach to the human performance analysis and its place within the program.

2.1. General Concept of the Proposed Precursor Event Analysis Program

The general conceptual framework of the proposed precursor analysis program as well as the place of the evaluation of human performance in it is shown on **Figure 1.** The objectives of the precursor program are almost the same as those that the NRC identified in its Accident Sequence Precursor (ASP) Program [1]. The two main objectives are as follows:

- determination of the risk significance of the operational events on different levels of risk (e.g. core damage, system/component unavailability, etc.), identification of the most significant ones and their ranking,
- early signalization of negative trends in performance.

In addition, the following secondary objectives have been defined:

- drawing conclusions based on the impact of the operational events on the risks at different levels
- feedback to the PSA model, i.e. identification of necessary model developments or data modifications.

In order to meet the above objectives the following "action plan" was set up:

- develop a method and a tool capable of determining the impact of a given operational event on the core damage risk
- apply the method and the tool for the events reported to the authority (trial application)
- develop and analyse risk based safety indicators associated with different levels of risk that are capable of giving early signal in the case if any of those risk levels changes significantly
- develop a tool for the evaluation of the set of risk based indicators of different levels
- apply the risk based safety indicators for all operational events in a given period (trial application)
- finalise the set of risk based indicators and make any modifications to the methods and tools found necessary during the trial applications
- implement the precursor analysis system.

The approach applied by the NRC in the ASP Program has been chosen as a basis for the proposed precursor event analysis scheme. The methodology and the analysis process of the ASP Program has been reviewed and adopted with some modifications reflecting specificities of the proposed precursor analysis system. A computer software has been developed to make the process of evaluation of the core damage risk as "easy" as possible. Of course, not all the modelling approaches and techniques could be computerized, there is still a need for deep understanding of capabilities and limitations of the PSA model and assumptions. Trial application of the methodology and the computer tool is underway.

As a next step, several risk based indicators have been defined and analysed. Analysis of these indicators was performed by simulation of failure events and it included the following phases:

- determination of how well they estimate the underlying nominal risk level,
- analysis of their behaviour in the case of a step change (increase) in the underlying risk level,
- analysis of their effectiveness with regards to indicating different changes in performance, i.e. (1) determination of the probability of detection of a real change together with the associated average run length (average number of steps until detection) and (2) determination of the false alarm probability (probability of detection of a change when there is no change at all),
- selection of the optimal indicators based on cost-benefit analyses.

These are the tasks performed so far within the precursor program. All the others listed before are currently under consideration.

2.2. Types of Interactions Analysed

Quantitative evaluation of the human performance in operational events is supposed to be performed as part of the precursor event analysis program as shown on **Figure 1**. The evaluation should be based on the results of the qualitative evaluation process, i.e. all the information relevant to the human peformance should be extracted from the Licensee Event Reports. These pieces of information are mainly concerned with the qualitative evaluation of human performance, in particular with knowledge adequacy of the personnel for the given situation, quality

and availability of procedures, man-machine interface, workload, etc. Human interactions performed in an operational event may be modelled in the PSA, but they may be missing from it. In this respect, four types of possible relationships have been identified between the human interactions in an operational event and the actions modelled in the PSA. These are the following:

1. *An error committed during the operational event and it is modelled in the PSA.*
   - In this case the basic event describing the given error has to be set to "true" event during the PSA based event evaluation. HEP value of the given basic event also has to be studied from the point of view of: if it is low, how the error could occur at all. In such a case HEP value might have to be revised.

2. *An error committed during the operational event and it is not modelled in the PSA.*
   - In this case appropriate risk level of the error has to be defined deterministically first, i.e. possible place of it in the PSA model has to be identified. A "true" event has to be added after that to the place identified in a correct logical connection with other basic events. In addition, risk significance of the error has to be studied, i.e. characteristics of its contribution to the core damage risk, such as fractional contribution (or Fussel-Vesely importance), risk achievement worth, risk reduction worth and sensitivity factor have to be determined. The need for the modification of the basic PSA model (adding the above basic event describing the committed error once for all) has to be decided based on these characteristics.

3. *No error committed during the operational event but one (or more) of the errors modelled in the PSA is (are) challenged*
   - In this case the HEP value has to be studied from the point of view of its appropriateness for the given situation. Some conditions may differ from those considered during the identification of the "average" HEP value for the given action, that requires modification of this basic value.

4. *No error committed during the operational event and none of the errors modelled in the PSA is challenged, but a postulated additional human error would lead to an undesirable state*
   - In this case the postulated error has to be modelled by adding a basic event describing that error to the appropriate level (and in appropriate logic) of the PSA model and determining its probability. Furthermore, risk significance of the error has to be analysed by the characteristics of its contribution to the core damage risk. If the error appears to be significant then it has to be added to the model once for all, while in the opposite case it can be just left out.

As it can be seen, modelling of human performance may require the following modifications of the PSA model:

- model modifications (cases 1, 2)
- data modifications (case 3)

- model and data modifications (case 4 and cases if more than one error modelled in the PSA are challenged by the operational event)
- none (if no human interactions are performed during the operational event or the interactions performed are not related to the PSA model at all).

2.3. Modelling Approach

The approach selected for modelling human performance depends on the type of actions of interest. The types of actions modelled in the Level-1 PSA are as follows:

- type A: pre-accident actions
- type B: initiators
- type C: post-accident actions.

Type A
Pre-accident errors were analysed by using a modified ASEP procedure that took into account the specifics of VVER operation. The study included a number of talk-through analyses with extensive involvement of plant technical staff. A formalised procedure was adapted to collect information important to HRA and organise this information into a framework useful for quantitative assessment. The basic HEP estimates were derived mainly from the THERP Handbook and from the ASEP procedure guide.

The first step of the quantification process was the selection of a generic basic value for human error probability. This value was modified according to the existence or lack of recoveries from the anticipated error by a recovery factor that could be determined and quantified by identifying the so-called basic and optimum conditions that apply to the given interaction. The next step of the quantification process was the assessment of the so-called procedure factor under basic conditions. This was performed by the use of a logic structure taking into account the necessity, existence, usage and quality of the procedures applied for the given interaction. In addition to the recovery and procedure factors within-person dependence was also considered in the quantification process by determining a dependence factor for multiple interactions on parallel system trains considering separation of actions administratively, in time, or by location. As a result of the above process a HEP value was derived for each pre-accident action modelled in the PSA.

With regards to cases 1 and 2 above of the relationship between the activities in the operational event and the ones modelled in the PSA the only thing that has to be done during modelling of the error committed is setting the appropriate basic event to true event. In case 3 recovery, procedure and dependence factors have to be studied from the point of view of the differences of their values from the ones calculated for an "average" interaction in question. Basic and optimum conditions, specificities of the procedure usage in the given

situation and the real dependence effects have to be reevaluated for this reason. In case 4 a new "average" interaction has to be analysed by the given quantification procedure.

Type B
Initiator type errors were quantified in the Level-1 PSA by the use of plant specific data. The majority of these initiators were found to be those leading to an inadvertent reactor trip.

Case 1 in this context means that one of the initiating events included in the PSA model occurs due to a human error. In such a case probability of the given initiating event has to be set to P=1 and the CCDP is defined by the related event tree. All the other cases relate to situations when no initiating event has really occured but one (or more) of them is challenged by the human activity. The way of modelling depends on whether the person carrying out (or not carrying out) the given activity should have performed the activity and its omission has led to the situation challenging an initiating event or he has made an action by mistake and due to that one of the initiating events could have occured with higher than nominal probability. In the first case the initiating event is challanged passively while in the second - actively. For the first case the decision tree model developed for type C actions (see below) is applied. In the lack of an appropriate model for errors of commission for the second case expert estimates are to be applied.

Type C
Observations were made at the full scale replica simulator of the plant to help modelling and quantification of post-accident errors. Although the simulator study was originally aimed at developing and using plant specific TRC curves, the results of the data analysis showed that the use of such curves were not sufficient. This finding led to the development of a stand-alone model of crew reliability. This model is based on a decision tree approach, and it relies on both simulator data and expert opinion. The model, i.e. the decision tree directly shows the various factors that could influence crew reliability, the impact of these influences, their dependencies together with the probability values assigned to each branch. The influence of the following factors has been integrated into the decision tree:

- difficulty of scenario
- time available
- crew knowledge of situation
- quality of man-machine interface
- required degree of crew integration
- quality and availability of procedures.

In cases 1 and 2 the way of modelling of the error is the same as for type A actions, i.e. the basic event describing the given error committed during the operational event (an existing basic event in case 1 and a newly built-in one in case 2) has to be set to true event. In case 3

reevaluation of the above influence factors is required from the point of view of whether or not their average value is appropriate for the given situation. Case 4 requires evaluation of a completely new (from the point of view of the PSA model) operator action by the decision tree methodology.

3. FURTHER NEEDS AND DEVELOPMENTS

Up to day, qualitative evaluation of the operational events is performed by the plant, conclusions drawn and the necessary measures identified are included in the licensee event reports that are reviewed by the authority. The quantitative evaluation process is in a preliminary state, but it has already been understood that some pieces of information necessary for that - in particular for the human performance assessment - can be missing from the licensee event reports since criteria of what information should be included in it have been defined in the past without considerations about the possibility of PSA based event analyses. Such discrepancies should be resolved, new criteria describing the needs of not only the qualitative but also the quantitative evaluation should be introduced into the documentation requirements of the operational events.

Trial application of the method and the tool for determining the impact of a given operational event on the core damage risk is going on. This activity is performed within a joint work of the PSA team members from VEIKI with the staff members of the HAEC. Some conclusions could already be drawn, but they are not to be published yet due to their preliminary nature. This activity should be continued in order to gain experience in such kind of an evaluation process.

More risk based indicators should be defined and analysed, including ones that are capable of indicating changes in the human performance.

It is necessary to develop a tool for calculating values of risk based indicators, keeping them up to date and comparing them to given criteria. Information needs for them should be determined and the information pathway should be set up. Having the supposedly complete set of indicators a trial application is to be performed. Based on its results the set of indicators as well as the tool analysing them should be finalised.

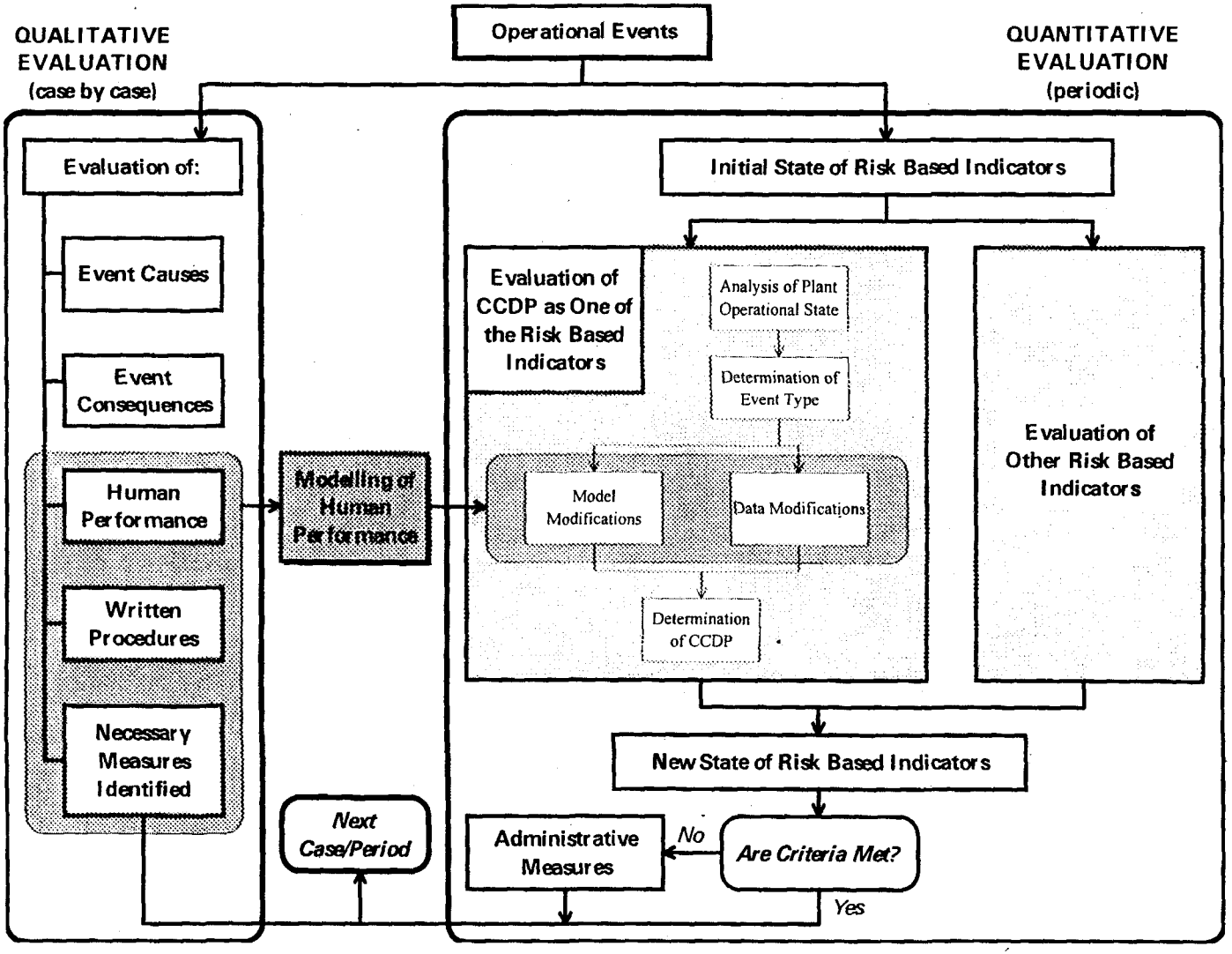

Figure 1. - Proposed Concept of the Precursor Event Analyses