International Conference
Nuclear Energy for New Europe 2003
Portorož, Slovenia, September 8-11, 2003
http://www.drustvo-js.si/port2003

Operational Experience Feedback with Precursor Analysis

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1 INTRODUCTION

Plant operational experience is a valuable source of information for improving the safety and reliability of nuclear power plants. Operational experience feedback (OEF) system manages this aspect of NPP operations' (safety) assessment.

The traditional ways of investigating operational events, such as the root cause analysis (RCA), are predominantly qualitative. RCA as a part of the OEF system provides technical guidance for covering the following areas: conditions preceding the event, sequence of events, equipment performance and system response, human performance considerations, equipment failures, precursors to the event, plant response and follow-up, radiological considerations, regulatory process considerations and safety significance. The corrective actions based on the RCA/OEF prevent recurrence of the event.

Analysis of the event and the selection of recommended corrective/preventive actions for implementation and prioritization can be enhanced by taking into account the information and insights derived from PSA-based analysis. A PSA based method, called probabilistic precursor event analysis (PPEA) provides a complement to the RCA approach by focusing on how an event might have developed adversely.

OEF approach, combining RCA and PPEA, for events at NPP Krško has been developed at SNSA with help of IAEA and NPP Krško personnel. The above mentioned OEF approach has been applied to selected operational events to demonstrate relevancy of such analysis and its advantages.

2 OPERATIONAL EXPERIENCE FEEDBACK PROCEDURE

Information regarding events are obtained from NPP Krško reports and plant personnel interview, SNSA inspections' reports and form other sources (e.g. experience and praxis form other plants). The process of OEF investigation is concerned with fact-finding not fault-finding. Schematic presentation of the SNSA OEF procedure for events originating from NPP Krško is shown on Figure 1. The events that should undergo in depth analysis are the ones rated at level 1 or higher on the International Nuclear Event Scale (INES) or theirs potential to increase the overall plant risk from all contributors is at least 1%.
SNSA OEF Quality Assurance procedure for events that occur at NPP Krško was prepared as part of the IAEA "Consultants Meeting on the Use of Information from Precursor Analysis for the Enhancement of Operational Safety" that has taken place at the SNSA headquarters. The procedure defines: purpose of OEF, its results and benefits, OEF information sources, responsibilities, RCA, PPEA, Effectiveness Review Panel.

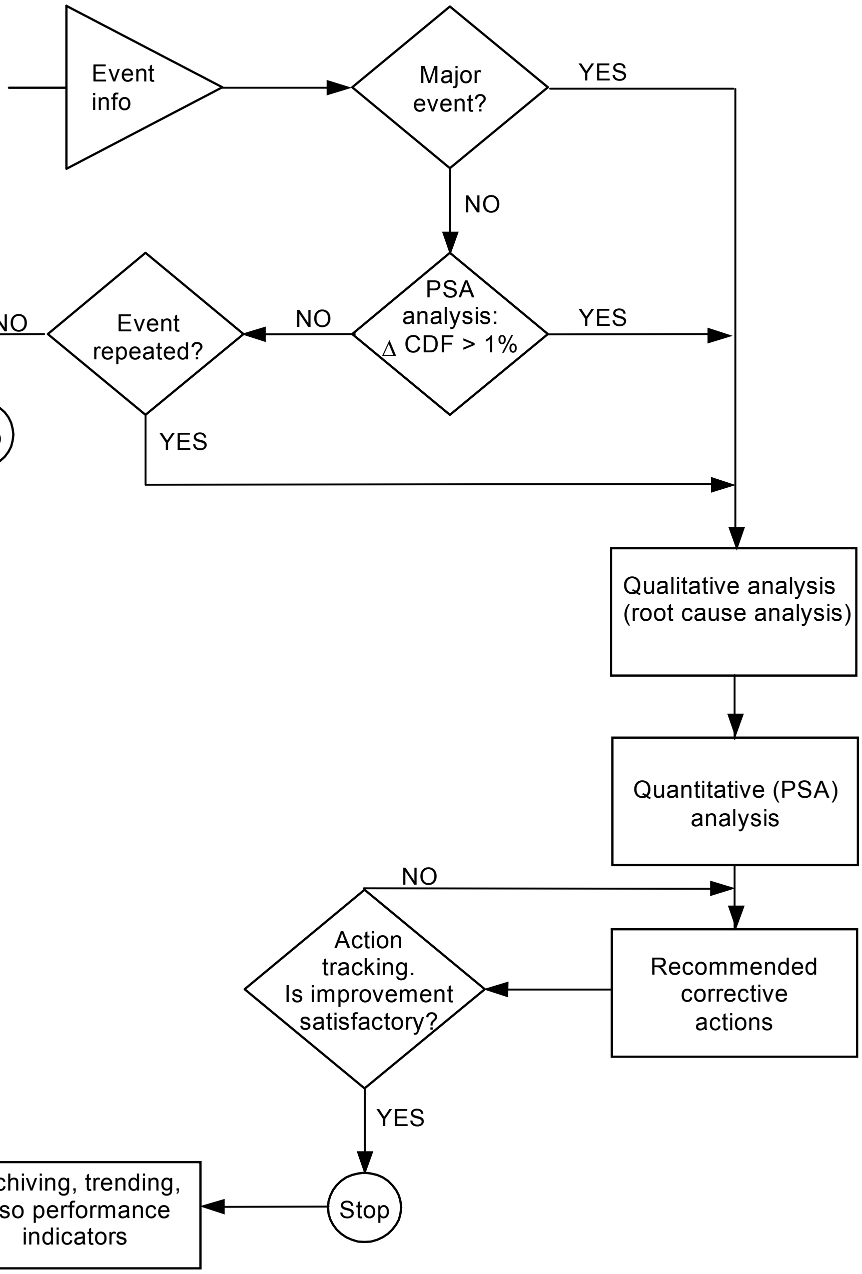

Figure 1: Schematic presentation of the OEF procedure

2.1 Root Cause Analysis

Deterministic RCA used in this procedure has been developed based on Ref.[1], [2], [3] and [5].

The first task in deterministic RCA is to develop Event and Causal Factors Chart (ECFC) as shown on Figure 2. On the ECFC the top Primary Event Line shows relevant actions and happenings that corresponds to question "What?". These are enclosed in rectangles except for things that are judged to be Primary Effects, i.e. undesirable equipment conditions or inappropriate human actions which are enclosed in a diamond shape. The Primary Event Line is conventionally a ‘time line’ advancing from left to right. To make its presentation clearer, the events that are a direct consequence of the previous event are marked so by a note above them.

At this stage in the analysis of the event, after determining the primary event line and before committing to further time and effort, an input from PSA specialists should give insights into the safety significance of the event if its overall rating is less than 1 according to INES.

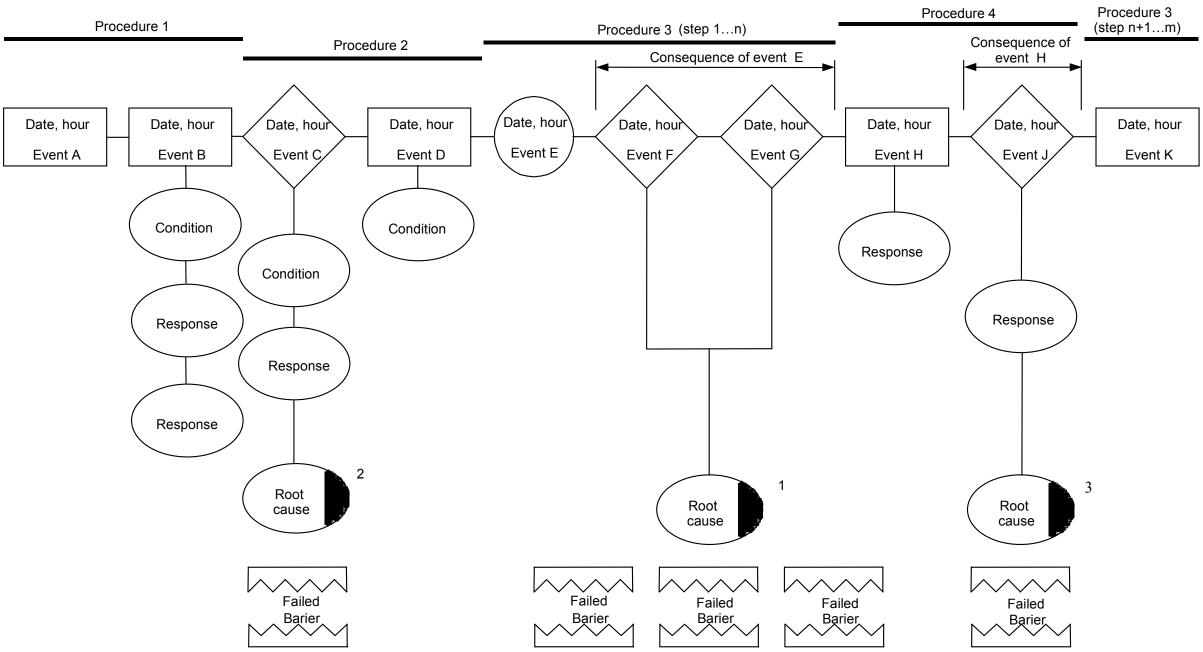

Figure 2: Event and Causal Factors Chart (ECFC)

If the PSA specialist estimates the potential increase to the overall plant risk from all contributors to be more than 1%, the event should undergo further in depth analysis.

Referring again now to the ECFC, above the Primary Event Line are presented the procedures (AOP – Abnormal Operating Procedures; EOP - Emergency Operating Procedures) that were used to master the events and/or mitigate the consequences of events. Procedure Line is SNSA's addition to the ECFC. Besides providing the data about the procedure being used at a particular time during the event, it also indirectly helps understanding operators' actions and their perception of the event.

Below the Primary Event Line alongside the term "How?" are placed conditions and behaviors that influenced the primary events, particularly the primary effects. These bits of information enable investigators to proceed logically from "What?" to "Why?" i.e. to derive causes. One way of achieving this is to use Cause-and-Effect analysis which, in its simplest form entails asking the question "Why?" repeatedly for conditions/behaviors until a cause is reached that cannot be influenced. With other words, the root cause of event is recognized when there is no known answer to question "Why has it happened?" regarding relevant condition that may have affected the event. At that point the OEF is proceeding by determining the corrective actions to be taken in response to events, utilization, dissemination and exchange of operating experience information and at the end reviewing the effectiveness of the OEF.

It is often useful to select 'causes' from a list. Such lists have been developed by IAEA/NEA for the Incident Reporting System (IRS) and also by WANO for its members. The causes are arranged in a hierarchy under Causal Factor categories and then Root Causes; once the category has been decided upon, then the most appropriate root cause can be selected from the list. Codes are assigned to the root causes and this makes such data easy to trend and manipulate. On the ECFC presented in Fig. 2 root causes are depicted as oval shapes with 'blackened' ends. It is common practice to discriminate between root causes by designating them as follows: '1' primary root cause, '2' contributory factor and '3'possibly relevant.

The logical output from a completed ECFC is a list of Specific, Measurable, Achievable, Realistic and Timely (SMART) corrective actions and possibly, preventive actions too. These corrective actions may be developed as a consequence of considering first the causes and secondly the barriers on the ECFC, and since these can be shown to link to primary effects, assurance is provided that relevant information is not overlooked

2.2 Probabilistic Precursor Event Analysis

PSA based event analysis provides, due to its quantitative nature, appropriate prioritization of corrective actions. This method consists of the mapping of an operational event on a probabilistic risk model of the plant in order to obtain a quantitative assessment of the safety significance of the event. PPEA defines requirements for PSA model and code, identifies input requirements and elaborates following tasks: pre-analysis, understanding the event, modeling the event, quantification, "what if" analysis, interpretation of results and conclusions and reporting. The probability of core damage conditional to the occurrence of the event is the main severity measure used in the PPEA.

PSA is first used already at the start of the OEF procedure (Fig. 1). The main purpose of including a PSA for the screening of the events is to bring in the PSA perspective at this early stage in the process to ensure that no operational events which could be potentially significant are lost for further consideration. If applicable, the method provides a rough first quantitative estimate of risk significance. In addition, the view on the operational events is significantly broadened already at this stage by bringing in also the overall knowledge from the PSA.

As there are many operational events which have to be scrutinized at this stage only a very limited effort can be spent on individual operational events. Thus, efficient methods to deal with the individual operational events are required and available. These are as follows:

- A PSA usually provides ordered lists of PSA related items such as equipment, systems and human interactions. These can be used for a fast check on whether an event falls within the PSA perspective.
- Most of the PSAs provide in addition to the lists of PSA related items numeric values for the importance of these items. This allows to make a very quick estimate of the risk significance for events which can be roughly depicted by failures of PSA related items such as deficiencies in equipment, systems or human errors.
- Simplified or condensed representations can be derived from the PSA to carry out a quick and approximate estimate for the risk induced by an operational event.

The criteria used to decide whether or not the event should undergo in depth analysis is based on whether or not the event has a potential to increase the overall plant risk from all contributors in a significant way, say more than 1%. If the potential increase is less than 1%, the event is from the viewpoint of PPEA not worth of further consideration. If the rough risk estimate is above the criteria described above, the event is recommended to undergo in depth (quantitative) analysis.

There are two main steps within the detailed, quantitative precursor analysis:

- Relating the operational event to the plant-specific or at least a plant-type specific PSA model and finding out whether or not the event can be adequately analyzed by PSA based models. Depending on the type of operational event, there are events which do not fall into the PSA perspective or cannot be treated in a useful way by this approach. If this is the case, it should be noted, shortly justified, an information notice sent to the person responsible for the overall event analysis and the process stopped here as far as PSA is concerned. Otherwise detailed analysis is carried out in the second step.
- Precursor analysis, mapping of the precursor on the PSA model, qualitative and quantitative evaluation, interpretation of results and derivation of insights.

The use of PSA based event analysis can serve two purposes:

- it can provide a numerical value for the risk significance of an operational event, and
- it increases the understanding of the plant vulnerabilities given the event occurrence. Basically, in precursor analysis a re-analysis of the PSA is performed under the condition that the operational event has occurred.

The work comprises the following steps:

- precursor event review and analysis: understanding the event, identify causes, important factors and develop the context of the event in terms of the PSA perspective.
  The objective of this step is to develop a thorough understanding of the precursor event and of its context. Gathering of additional information regarding the event and related plant design and operational features is usually needed for this step, but also for some of the following steps. The information includes the following items: initial status of the plant, chronology of events, equipment and system deviations, failures and unavailabilities, operating staff behavior, actions, deviations and errors, status of related procedures, systems which worked successfully, fast detection, successful recoveries.
- mapping of the precursor on the PSA, logic representation: relate the event and its implications to the PSA model. PSA models adequate? Revise, extend if necessary.
  In order to relate the precursor event to the PSA, the analyst determines which accident sequences are involved or could be involved, what fault tree models, basic events or operator actions are affected, and what recovery actions could be applied or are made impossible. In the mapping process the relation between the observed precursor events with the events described in the PSA models is established. Basically there are two types of precursor events:
  - The precursor event representing a transient which interrupts normal operation of the plant, thus there is a real effect on plant operation. In this case the event can be easily related to an initiating event of the PSA (if modeled) and the accident scenarios affected by the event are those developing from this initiating event.
  - The precursor event involves the unavailability or a degradation of equipment or systems without an immediate impact on plant operation. If the precursor event is related to one (or several) safety functions, a systematic survey of the principal scenarios on which the precursor event impacts needs to be done. First, all the initiators which require the affected safety function(s) need to be identified. In the event scenarios or sequences developing from these initiating events only the scenarios which entail the precursor event are retained.

  Precursor events which entail both, an initiating event and equipment or system unavailability, are also possible and both types of impacts need to be included in the subsequent analysis in a combined manner.
- quantification: estimate failure probabilities, if required perform human reliability analysis (HRA), adapt PSA reliability models.

This step consists of mapping quantitative precursor data onto the model developed in the previous step. The objective is to carry out the quantification reflecting the conditions given for the precursor event. This quantification should be conservative, but not excessively conservative. In practice this is done by listing the characteristics of each event or sequence.
The probabilities of the basic events, of other events of the model which had happened during the incident are set to one in general. Correct logic modelling of these events is necessary to obtain appropriate results. The probabilities of events which did not happen remain at the standard values of the reference PSA.

- initial evaluation: recalculate conditional core damage probability for all appropriate sequences.
  After assigning the appropriate failure data to the basic events and initiating events, the accident sequence conditional probabilities are calculated. The result of the initial evaluation are accident sequence expressions (in terms of cutsets[1]) sorted according to their conditional probability. At this point potentially important sequences which may be affected by incident recovery actions should be identified for the following step.
- recovery actions: determine potential recovery actions, model recoveries.
  The objective of this step is the determination of appropriate recovery actions to be applied to the accident sequences in terms of cutsets based on the conditions of the incident, personnel available, and plant operating and emergency procedures. The determination of the recovery failure probabilities may require detailed analysis.
- evaluation: calculate new importance including recovery actions, perform uncertainty and sensitivity analyses.
  The objective of this step is to carry out the evaluation of conditional probabilities for the accident sequences including the recoveries identified in the previous task. The risk reduction ratio indicates the amount of reduction in the conditional accident probability to be gained if the considered event is assumed to be improbable (failure probability = 0.0). The risk increase ratio indicates the factor by which the conditional accident probability would increase if the event is assumed to happen with certainty (failure probability 1.0).
- extension: what would happen if the event occurs under different conditions and context?
- interpretation, conclusions, insights, corrective measures.
  The objective of this task is to interpret and document the precursor analysis. The analysis information and results are reviewed to determine key contributors in terms of dominant accident scenarios, important components or operator actions.

2.3 Event Review Panel

Inputs to the Event Review Panel (ERP) are the outputs from qualitative deterministic analysis (the event investigation) and the quantitative PSA analysis. Consideration of both types of information provides a more objective basis for decision-making when it comes to select, which of the recommendations to implement and the timescale of the implementation. Assuming that all actions emanating from the ERP (corrective, preventive or reporting requirements), are entered into an Action Tracking System, a further function of the ERP is to provide a review of effectiveness, i.e. to monitor the timeliness of implementing corrective actions, to adjust the priority of corrective/preventive actions if this becomes necessary in the light of recent operating experience and to ensure that the completed actions are successful in preventing recurrence of the event.

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[1] Cutsets are the minimal combinations of failure events used in PSA to logically represent accident sequences.

3 CONCLUSIONS

The here presented OEF is already in use at SNSA, trial analysis of past events have been performed with it. The expected benefits from the use of such combined approach have been reached. Namely, it is easier to manage a problem that is quantitatively measurable. Also the decisions made on the basis of quantitative data are more objective than those based solely on qualitative data. So, there are apparent benefits to be gained by applying PSA techniques at two stages of the traditional Event Investigation process:

- at the stage where events are screened for significance;
- immediately prior to making decisions about placing actions following a deterministic investigation.

The benefits of this approach are:

- Application of PSA clarifies the safety significance of an event during the screening of the in-coming OE reports: thereby reducing the likelihood of screening out event information that is actually safety significant.
- Additional information is available to the decision-making process when it comes to determining, selecting and prioritizing recommended corrective actions for implementation.
- The data emanating from PSA could be easily trended.

ACKNOWLEDGEMENTS

The authors would like to thank the IAEA Consultants team (D. Stimpson, R. Gubler and M. Dušić) as well as NPP Krško personnel (I. Vrbanić and I. Stručić) for their help and support in developing the here presented OEF and performing of trial analysis with combined RCA and PPEA techniques.

REFERENCES

[1] Nuklearna Elektrarna Krško, "Root Cause Analysis", Procedure ADP-1.1.203, rev.0, Krško, November 1995

[2] Nuklearna Elektrarna Krško, "Operating Experience Assessment Program", Procedure ADP-1.1.200, rev.4, Krško, January 2001

[3] International Atomic Energy Agency, "Use of Information from Precursor Analysis for the Enhancement of Operational Safety" Working Material IAEA-CS-59, Vienna, December 2001

[4] International Atomic Energy Agency, "The Combined Use of Deterministic and Probabilistic Methods to Enhance the Event Investigation Process at Nuclear Power Plants", Working Material IAEA-CS-60, Vienna, December 2001

[5] International Atomic Energy Agency, "A National System for Feedback of Experience form Events in Nuclear Power Plants", Draft Safety Guide, Working ID DS 288, Vienna, March 2002

[6] PSA analysis: "A framework for the PSA-based analysis of operational events", ENCONET, 1997