Techniques for Human Reliability Assessment in PRA

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Abstract

This paper discusses various techniques of Human Reliability Assessment in Probabilistik Risk Analyses, which have been applied by GRS. These techniques range from qualitative to quantitative techniques. The experience gained from the application of these techniques is presented and some specific problems identified by their application are reported.

1. Introduction

The assessment of human reliability has gained an increasing importance since the relative influence of possible errors of operators or maintenance personnel on the safety of nuclear installations has been recognized. In the follow-up of WASH-1400 and of the TMI accident many PRAs and operating experience have emphasized this. Especially, the analysis of the operating experience, performed for the US-ASP. (Accident Sequence Precursor)-Programm /1/ as well as for the plant-specific German Precursor Study /2/ support this conclusion.

This paper presents an overview about the general methodology and the techniques of human reliability assessment. The experience of GRS with human reliability techniques will be described. Finally, the data problem will be discussed.

2. General Methodology of a Human Reliability Analysis (HRA) for Nuclear Power Plants (NPP)

In Probabilistic Safety Analysis (PSA) HRA aims at identifying and evaluating staff actions affecting safety, which could have unfavourable consequences for the safety of the plant, if incorrectly performed, or if omitted.

Therefore, human tasks performed under normal operating conditions and those performed after accidents or abnormal occurences are to be considered. During normal operation errors might be committed during or after maintenance, repair, calibration, or testing or in the normal operation of the plant. These errors may occur in or outside of the control room. After an accident, most of the system-safety-related errors occur in the control room.

In each situation, the analyst considers mainly errors made when following plant procedures. These procedures can be written in the operation manual, they can be given orally, e.g. by the shift supervisor, or they can be standard shop practices, e.g. developed from the operating experience.

Little attention was paid to diagnosis and decision making errors in earlier PSA-applications, but after the TMI-2 accident several attempts have been made in order to consider such errors in PSA.

Extraneous acts are normally of minor importance for human reliability analyses. On the one hand there is a very great number of opportunities to interfere with the systems by performing extraneous acts, but on the other hand there are many technical and administrative provisions (e.g. interlocks, priority modules, access only for authorized personnel) taken to prevent such actions or at least to prevent serious consequences.

Malevolevent behaviour, like sabotage, is normally not included in a HRA.

This means that for the identification of actions affecting safety, only those actions have to be considered in PSA whose ommission or incorrect performance

- would lead to the initiation of transients or accidents (so-called initiating events),
- would affect the availability of systems required for preventing or controlling accidents, i.e. limiting their consequences,
- and also those actions required for controlling the accident after being occurred.

The first group of actions, whose incorrect performance or omission would lead to an initiating event, has only to be considered, if there are no data available from the operating experience with respect to the frequency of the initiating events, because such data already include contributions from human error.

The general methodology which has to be applied for an HRA in a PSA, can be described according to the Probabilistic Risk Assessment (PRA)-Procedures Guide /3/ by the following four phases:

1) Familiarization
2) Qualitative Assessment
3) Quantitative Assessment
4) Incorporation

In practise these phases are not independent, many iterative steps are necessary the more detailed the analysis is becoming.

During the familiarization the analyst normally is collecting general information about the tasks being analyzed and evaluated. In the qualitative assessment the performance requirements and objectives have to be defined as well as the factors which have an important impact on the quality of performance, i.e., the performance situation. Depending on the task characteristics even some modelling of human performance is required, e.g. modelling of dependence or scanning modells.

Potential human errors have to be identified. Finally, the error probabilities have to be determined and the quantitative influence of the various performance shaping factors has to be assessed. In the last phase, the results of the HRA have to be incorporated into the overall system analysis and if required a sensitivity analysis can be performed.

For a more detailed description of this general methodology reference is made to the PRA-Procedures Guide resp. to the Handbook of Human Reliability /4/.

3. Techniques for Human Reliability Assessment in PSA

Various techniques are available to meet the requirements of the described methodology. In the following only these techniques are described, which have been applied by GRS.

3.1 THERP-Technique for Human Error Rate Prediction

THERP is probably the best known and most widely used technique for the systematic investigation and evaluation of human reliability. For a detailed description of the THERP-procedure reference is made to /4/.

The input into the general system fault trees are human error probabilities for the task or sequence of tasks of interest. These values are derived from a specific form of probability tree diagramming, the HRA-event tree diagramming.

These HRA event trees represent a chronological order of the task elements or of the sequence of the tasks, to which success resp. failure probabilities are assigned.

According to our experience the most striking advantage of THERP is the relatively detailed task-analysis, which is required by the method. The analysis of the safety-relevant tasks in the German Risk Study revealed some deficiencies in the technical and ergonomic design. The most important consequence was the automatic control of the 100 K/h-cool down procedure after a small leak in the primary circuit. Further improvements concern the status-feedback of valves and the operation manual.

THERP is combining elements of event sequence analysis, of faulttree analysis and the method of ergonomic task analysis.

3.2. Event sequence analysis technique

Starting with a defined initiating event (e.g. a pipeline rupture), event sequence analysis determines the various possible consequences of the event, via the success or failure of the countermeasures which being are required then.

Only such event sequences have to be investigated which essentially affect the safety of the plant, and which could, for example, lead to a core meltdown or degradation.

These system functions contain both automatically initiated technical functions (e.g., fast shutdown) and manual interventions by staff (e.g. initiation of a cooldown at 100 K/h in the event of a small leak in the primary coolant system).

Actions of the staff affecting the frequency of the precursor events (transients or incidents) are mostly not determined in this way. Such actions are often not explicitly investigated in risk studies as discussed earlier.

Actions affecting the availability of systems required for preventing, controlling or limiting the consequences of incidents are normally identified and analysed in the reliability analysis of the required system functions.

The event sequence analysis thus in the first place identifies actions directly required for controlling the incident. It provides only relatively approximate qualitative information: a detailed analysis of these actions is also given in the reliability analysis which is dealt with later on.

Event sequence analyses were used by the GRS to a fairly large extent in the "German Risk Study" and also in the SNR-300 Risk Study.

3.3 Failure Mode and Effect Analysis (FMEA) applied to HRA

FMEA is an inductive systems analysis procedure. Starting with a given task, all possible types of error are investigated with regard to their consequences. In complex tasks the applicability of such a procedure rapidly reaches a limit.

However, for small and narrowly specified tasks, like miscalibration of measuring channels, FMEA was applied by GRS as a very useful qualitative aid for identifying potential human errors affecting the systems reliability.

3.4 Fault Tree Method

The fault tree method is certainly the most frequently used procedure for reliability analysis and reliability evaluation. Starting with the top of the fault tree normally representing the failure of the system or the system function, all fault combinations of the system elements which could lead to this failure are considered downwards. Indeed, only the 2 states, function or failure, are considered; deterioration of the function is not normally considered in fault tree analysis.

Not only those actions required to control the transient or incident as in an operating handbook are considered, but also those affecting the availability of particular components or system functions (e.g. maintenance measures).

Complex actions, sequences of actions (e.g. a test procedure) or team actions have to be broken down into individual action elements until reliability indices can be allocated. Possible dependencies have to be considered and modeled.

Thus, fault tree analysis is including in a deductive procedure all relevant staff actions for the failure or non-availability of the system or system function.

A few remarks can be made to the practical application of this technique. The task of identifying potential human errors should not only be assigned to the system specialists. It has been proven to be effective, that even the human reliability specialist analyze the systems for potential human errors. The following reasons were leading to this conclusion. The system specialists mainly consider first order failures, whereas even a chain of errors given a strong dependency between the separate actions or an interrelation between some tasks can lead to a relatively high overall probability of human error. The potential for an human error is sometimes difficult to see and requires to know the characteristics of human behaviour. On the other hand the knowledge about human reliability data allows sometimes to neglect potential errors, e.g. when the error probability is low and the probability of recovery is very high.

Another problem in the practical application can be addressed to the decomposition of complex tasks into individual steps. Quite often there is a lack of detailed and definitive task descriptions, thus the analyst has to make assumptions, which increase the uncertainty of the evaluation. Thus again the great importance of a sufficiently detailed task analysis is stressed.

3.5 Task Analysis

Taks analyses are used to determine the demands on staff resulting from the tasks. They represent one of the fundamental analytical methods of ergonomics. With reference to /5/ a task may be defined as a set of human behaviours with common features required for the achievement of a specified goal.

Task analysis is used to determine the behaviour elements needed for the fulfilment of the task and to determine the factors incluencing the behaviour elements, too.

A simplified task analysis was carried out as part of phase A of the German Risk Study and for the German Precursor Study. According to our experience very often the information from the system specialists or from the operation manual about the tasks to be performed is not detailed enough for an thorough analysis.

This gap has to be filled by the experience and quite often by judgement of the HR-analyst. This can be overcome to some extent, if the HR-analyst has the possibility to observe performance of typical tasks in the plant, to discuss the tasks with the staff and also to participate in simulator courses.

3.6 Evaluation of Operating Experience

The evaluation of operating experience is not an independent technique within HRA analysis, but it makes a very important contribution to the identification and analysis of operator error. For this reason, it will be discussed here separately as a technique:

Evaluation of operating experience mainly is given by the following indications regarding human error:

- weak spots in the system favouring human error;
- weaknesses in the system concept leading to excessive demands on limits of human performance;
- tasks or influences of activities which otherwise are mostly not accessible to systems analysis;
- team behaviour of staff in the control room;
- nature and time of reactions of staff with the occurrence of various transients
- preferred staff strategies in the control room;
- operator experience.

A quite detailed evaluation of operating experience with respect to human error has been carried out on several selected examples in the German Precursor Study. This analysis was based on reported events and on discussions with the plant staff, many additional information from system descriptions and transient analyses was also used.

The study showed that about 50 % of the events selected as precursor had been influenced by human error. These events contribute about 67 % to the mean value of the overall frequency of potential severe core damage accidents of $4.7 \cdot 10^{-5}$ per reactor year. Moreover, it has yielded, that errors of the operating personnel are dominated by errors in situation assessment, that means errors in assessing the consequences of an action.

Errors during maintenance, test and repair are dominated by the categories "errors of identification" (e.g. reading errors) and "errors due to forgetting".

Furthermore this study provided interesting indications regarding subsystems, whose complexity favors human errors. Additionally insights into preferred operator strategies in specific precursor events have been obtained.

4. The Data Problem for HRA

It is generally agreed among HR-analysts that the dearth of human performance data from which human error probabilities could be derived is a major problem for HRA. But there is some effort especially in the USA to improve this situation by installing a data collection system and a pertinent data base.

The best available source of Human Reliability Data with respect to NPP operations is currently the "Handbook of Human Reliability" /4/. The data presented there are derived from NPPs, from dynamic simulators, from various industrial and military sources, from field studies, from laboratory experiments and to a great extent even from subjective expert opinion.

These data refer mainly to the situation at US-NPPs. Thus, for our analyses the data had to be modified and adapted for the German NPP situation, which is different in the degree of automation, in the control room design, in administrative regulations and in many other aspects. Since there is nearly no data available on which such modifications could be based, subjective estimates play an important role. This situation could only be improved, if for the German reactors a human performance data collection and data bank will be installed.

It has been proven to be useful, to support the assessment process by an thorough review of performance data reported in the ergonomic literature. It may be quite often helpful, to decide, whether a specific action is well in the range in which successful human performance can be expected or whether it puts demands on the human performance being close to human limitations and thus lead to high human error probabilities. There is some debate, whether models of human performance can help to reduce the reliability data problem. GRS is planing to study these models in more detail as part of its future research in the HR-Field.

5. Conclusion

The following conclusions can be drawn from our experience. Many techniques are available for the qualitative and quantitative analysis of human performance in NPP's. These techniques can provide a good understanding of the human role in a NPP and can be used effectively in connection with ergonomic data to identify weakpoints in the ergonomic design. Especially the task analysis, if extended and detailed further, will be an excellent tool for this purpose.

The quantitative assessment of human reliability still requires further research efforts with respect to both, the models and the data. A significant progress can be expected, if a comprehensive data collection and data bank is installed. The current status of the quantitative techniques can provide sound results for the area of skill and rule based behaviour, but especially the knowledge-based domaine of human performance still needs extensive investigation. Currently not more than gross subjective estimates for such tasks can be offered.

Despite these problems, which in no case are listed completely, HRA can provide important contributions to a further increase of safety, availability and economy of the NPP's. The relatively high standard of methods and data applied in PSA to hardware problems requires a corresponding progress in the field of HRA, otherwise the validity of PSA-studies could be limited.

But there are many good reasons to believe that this goal can be reached, since the ways to overcome many of the problems are known.

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