Evaluation of Existing Applications and Guidance on Methods for HRA – EXAM-HRA

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Abstract

Are there actual differences in plant features that explain why human reliability analysis (HRA) results differ between plants for similar actions or is this merely a result of differences in the HRA with respect to choice of method, analyst judgment, PSA scope, resources spent, etc.. Identifying discrepancies in HRA applications is the first step in finding these answers. EXAM-HRA is a Nordic, Swiss and German project which assesses human reliability analysis (HRA) applications in existing probabilistic safety analysis (PSA) studies. The overall project objective is to provide guidance for a "good praxis" HRA for purposes of PSA to ensure that plant specific properties are properly taken into consideration in the analysis and to provide means to improve plant features based on HRA results. This includes identifying discrepancies and actual aspects explaining why differences in results can be observed in HRA applications. The guidance developed in the project shall also provide means to improve the experience feedback on plant features based on HRA and PSA results.

The project is performed in 3 consecutive phases. The objective for the first phase is to provide a framework for identifying discrepancies in existing HRA applications. This includes development of a survey and screening process for operator actions in existing PSA studies as well as development of an evaluation guide. The second phase consisted of performing the case studies using the evaluation guide resulting in observations that allow for improvements of both plant features as well as the HRA itself. In the third phase additional assessments were performed in order to generate more comprehensive observations. The final reporting of the EXAM-HRA project provides an overview of the assessments done by developing a guidance document.

The evaluation format that has been developed within the EXAM-HRA project has been found useful and the assessments of actions performed in the case studies has resulted in findings regarding plant features as well as features of the HRA and PSA applications. The final reporting provides an overview of the assessments done by developing a Practical Guide to HRA. The recommendations presented in the Practical Guide are based on the experience gained from the case studies and the findings regarding plant features as well as features of the HRA and PSA applications. The recommendations made for the HRA process are supported by specific observations from the case studies.

The aim is to improve consistency in in-depth HRA and human error probability (HEP) assessment by providing a common basis for methods and guidance for HRA application and assessment. These results are used in the final phase of the project to define good practice and provide guidance for inclusion of plant specific aspects in HRA applications in the context of PSA. This overview and the practical recommendations on good practice shall support the assessment of plant specific aspects in HRA and ultimately improve the plant risk.

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I. INTRODUCTION

In nuclear power plants, humans have a major role in maintaining the plant in a safe state as well as, in certain scenarios, bringing the plant back to a safe state. Human reliability analysis (HRA) is an important tool for assessing the human contribution to failures, given the surrounding environment in which the humans operate. The EXAM-HRA project has during 2010-2015 been a Nordic, Swiss and German collaboration project[9], in which existing HRA applications have been assessed and compared in order to identify areas for plant improvement. The main goal of the project has been to produce a guideline for a state of the art HRA for PSA purposes, based on performed assessments, ensuring that plant specific properties are properly taken into account in the HRA.

The project has been performed in several consecutive phases, including the following main parts:

- Phase 0: Preliminary survey and project program
  - Survey of operator actions in existing HRAs
  - Development of an evaluation guide for assessment and comparison of operator actions
- Phase 1: Survey and initial assessment to find discrepancies
  - Assessment of operator actions
- Phase 2: Reassessment and actual plant aspects
  - Reassessment of operator actions
  - Conclusions for plant improvement
- Phase 3: Guidance
  - Guidance for HRA applications

The final reporting of the EXAM-HRA project provides an overview of the assessments done by developing a “Guidance on methods” document, see Figure 1. This is presented in the form of a Practical Guide to HRA [27] based on experience from the survey, evaluations in case studies and reassessments performed within this project.

The human failure events (HFE) presented in the survey report and application framework has been used to develop a “Guidance on scope” document presented in the Application Guide [25]. The Application Guide is summarized in section 4 in this report.

The overall project objective is to provide guidance for a ”good praxis” HRA for purposes of PSA to ensure that plant specific properties are properly taken into consideration in the analysis and to provide means to improve plant features based on HRA results.

This includes identifying discrepancies and actual aspects explaining why differences in results can be observed in HRA applications.

The context created by the plant specific properties is hereafter referred to as “plant features”. The guidance developed in the project shall also provide means to improve the experience feedback on plant features based on HRA and PSA results.

[9] The contributing organizations are the Nordic PSA Group (NPSAG) in this project represented by Forsmark NPP (FKA), Ringhals NPP (RAB) and Olkiluoto NPP (TVO), SSM, Vattenfall, the Finnish research program SAFIR, VTT, NKS, VGB, Brunsbüttel NPP (KKB), Krümmel NPP (KKK) and Mühleberg NPP (KKM).

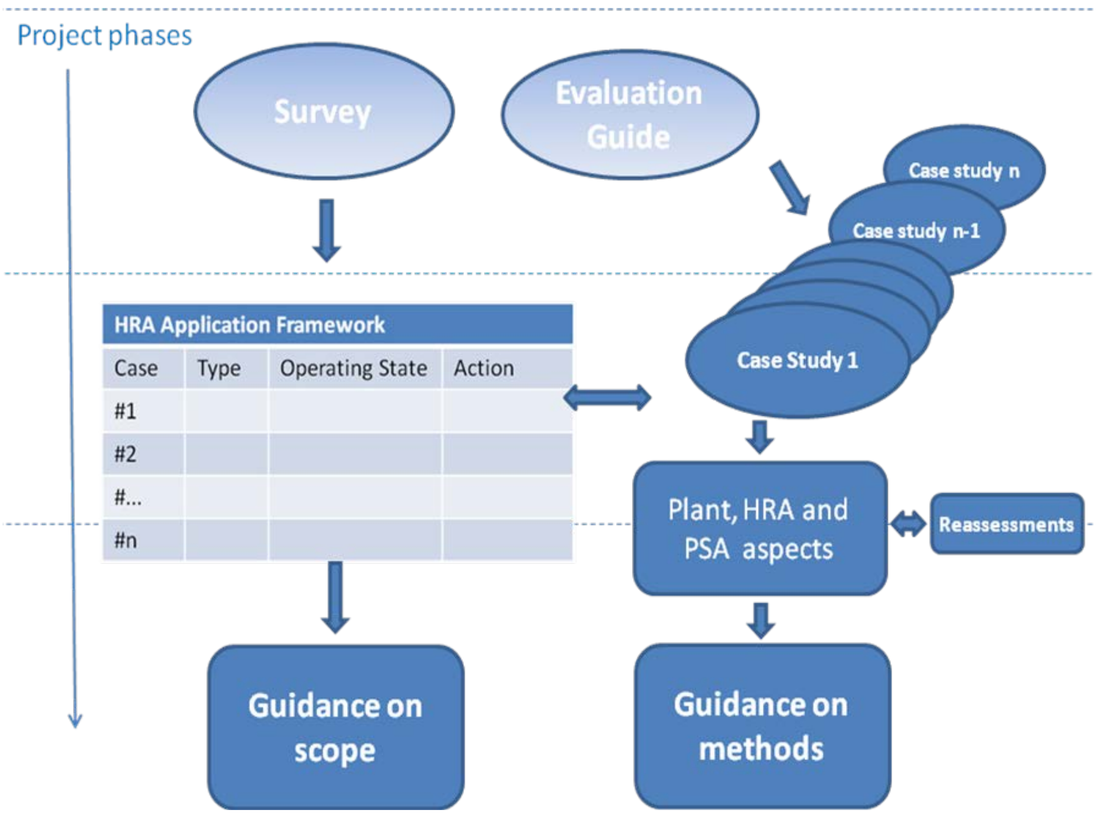

Figure 1. EXAM-HRA project overview

II. SURVEY ON OPERATOR ACTIONS IN EXISTING HRAS

The performed survey has collected approximately 420 operator actions from six plant specific PSAs. The main part of the operator actions collected in the EXAM-HRA project are so called post initiators, i.e. operator actions credited after an initiating event.

In order to condense the operator actions into comparable groups, the actions are grouped based of the following aspects:

- Action type, i.e. pre initiator, initiator or post initiator
- Operating mode
- Level 1 or level 2 PSA
- Credited for specific initiating event (where applicable)
- Action aiming at maintaining specific safety function (where applicable)

The work with the survey has resulted in a set of 66 groups of typical operator actions, which represent more than 300 of the operator actions originally included. These groups of operator actions form the HRA application framework, which consequently can be used for initial assessment of the PSA and HRA screening process. On the one hand, operator actions are in some cases not assessed as they are conservatively not credited in the PSA. On the other hand, operator actions might in some cases be absent due to a lack of completeness of the PSA. Hence, checking the inclusion or motivating the exclusion of the representative set of operator actions is a simple and effective method for assessing completeness.

With the survey as a basis, three cases of operator actions were initially chosen for further assessment. These were later supplemented by four additional cases, see section V. In addition, two plant specific reassessments have been performed for one of the actions. As the reassessment is performed specifically for a given plant, differences between plants are removed and focus is instead on differences in methods. Different methods, however, yield different insight in plant features, as they explicitly model different aspects. Thus, additional insights in the HRA applications for both plant improvement and guidance purposes have been obtained from the reassessments, see section VIII.

Using the described process for grouping a number of candidate scenarios and actions have been identified which can be included in the EXAM-HRA assessment. The screening report [3] presents the development of a generic tool based on survey results for selection (and identification) of scenarios and actions to be included in a PSA and assessed by an HRA. This tool can be further developed into a HRA application framework representing "all" relevant operator actions. The framework can provide guidance on the scope of HRA applications.

III. EVALUATION GUIDE

The starting point of the evaluation is the selection of representative scenarios. Thereafter the HEPs and how they are quantified is compared. Finally, the evaluation involves a comparison of how HRA related plant features are treated in the PSA and what impact those plant features have on the overall PSA results. The overall process is described in Figure 2.

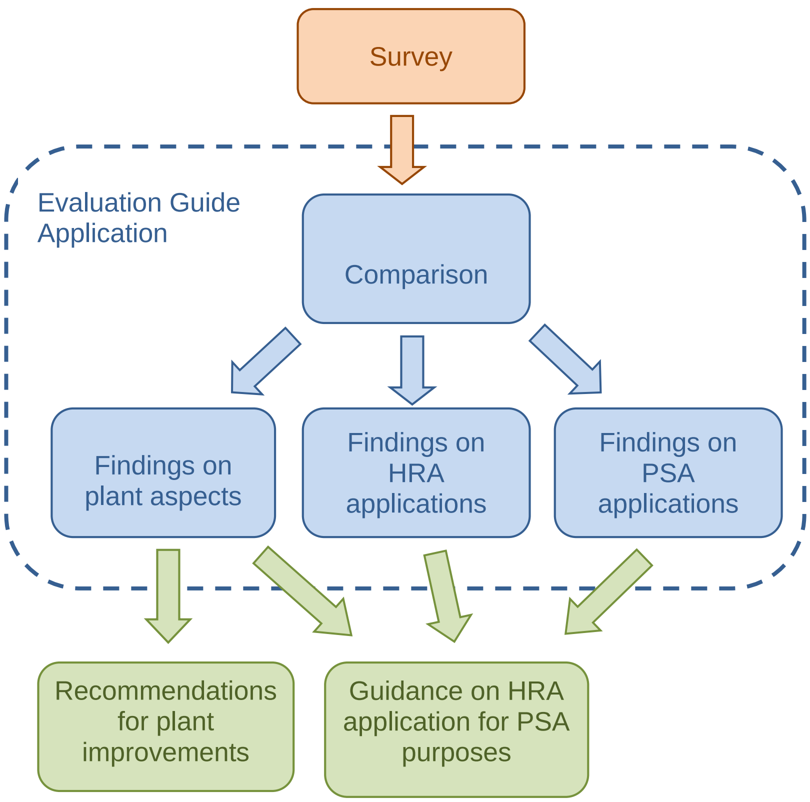

Figure 2. Evaluation guide framework.

A number of considerations for comparison are specified in the "Evaluation Guide" [4]. These considerations shall be answered when applicable. Additional aspects can be taken into account if it helps the understanding of the scenario or the HEP development.

The evaluation guide is to be used for assessment and comparison of operator actions and specifies information which might be of importance in the comparison. This part of the work can consequently also reveal areas of missing, unclear or incorrect information in the HRAs.

The following aspects are considered in the assessment:

- Scenario context, including general information of plant status, strategy for success, other tasks to be performed by same staff etc.
- Task context, including time windows, staffing and organization, performance shaping factors (PSFs) etc.
- PSA and HRA applications, including definition of task, methodology used, modelling applications etc.

- Resulting data, summarizing human error probability (HEP) values and importance measures.

The aim of the comparison is to identify actual plant differences, which can be linked to technical aspects, such as system and component configuration, as well as human factors related aspects, such as procedures, indications and staffing.

IV. APPLICATION GUIDE

HRA application framework

The application guide [25] is intended to provide guidance of the scope of HFEs (human failure event) to include in the HRA (human reliability analysis) applications in a plant specific PSA level 1 or 2 in order to improve the consistency of in-depth HRA and HEP (human error probability) assessment. Accordingly, this report is the result of performed survey and case studies in the EXAM-HRA project and presents an overview of operator actions represented by HFEs which are recommended to be covered in an HRA.

The HRA application evaluation includes the following tasks:

- By using the results from the survey of existing applications, an HRA application framework can be presented where for each HFE a context description can be formulated. This to provide a framework for screening and identification of candidate HFEs, including examples from the survey. Here a categorisation of the actions must be performed in order to identify groups of operator actions to compare. The initial grouping is based on action type, i.e. pre-initiator (Category A), initiator (Category B) or post-initiator (Category C).

- By using the check list developed in the project to assess the rationale for inclusion or exclusion of actions in the PSA model in question the scope of operator actions represented by HFEs can be justified. The check list can be used initially as a part of the PSA model development or at a later stage as a part of a PSA model review.

The application guide can be used as a tool for identification. By following the guide means are provided to get an understanding of how the HFE scope has been defined and how analysed operator actions have been chosen.

HFE context descriptions

The aim of the HFE context description is to give an understanding of the plant model and the preconditions for a specific operator action and aims at reaching an understanding of when and why the manual action is required. In the application guide [25] is the HRA application framework from the different plants compiled into an overall scope, i.e. list of HFEs, with a HFE context description of how other plants have done it:

- What is the operating mode?
- After which initiating event is the action considered?
- What is the overall task to be performed?
- In what scenario context does the action appear, i.e. when is the action relevant?
- HRA/HFE, definition of operator action

Check list for reasoning for inclusion or exclusion of actions

A practical tool in form of a checklist has been developed in the project, see [25]. This check list shall be used for checking the rationale for inclusion or exclusion of actions in the PSA models. The idea here is that an evaluation of the scope of HRA application is performed based on the check list and applied on each operator action identified in the project survey. The check list can be used initially as a part of the PSA model development or at a later stage as a part of a PSA model review.

In the application guide [25] the outcome of the survey and case studies performed in the project is presented in listing of HFEs considered. These lists can be seen as recommendations of HFEs that should be covered in an HRA in order to reflect the plant features as good as possible.

Table 1: Check list for reasoning

Why excluded?	
Reasons relating to plant design.	
	Action not possible in specific plant design.
	Action is possible, but time is too short.
	Action is possible, but it is too complex to benefit from.
Reasons relating to PSA concept.	
	Action is not credited, because it is a backup to an automatic activation.
	Action is not credited, because it goes into an "and-gate" with some other event with low probability.
	Action is neglected, because it goes into an "or-gate" with some other event with large probability.
	Action is not credited, because it is known not to contribute to PSA results.
	Action is not included into the model to keep PSA logic simple.
	Action is beyond scope of PSA.
Reasons relating to methodological constraints.	
	Action is not credited due to lack of written procedures.
	Action is not credited, because the method used is not applicable (e.g. too many skill based or knowledge based aspects).
	Action is not credited, because too little is known about the context, or the context is too variable to obtain a probability value.
	Action is not credited, because it would yield too small total HRA contribution to a SINGLE minimal cut set.
Administrative reasons.	
	Action could have been credited, but there was lack of time.
	Action could have been credited, but there was lack of other resources.
None of the above; please specify.	

V. ASSESSMENT OF OPERATOR ACTIONS

The following operator actions were chosen for assessment, based on the survey as described in section II:

- Closing of lower containment air lock [5].
- Manual restoration of residual heat removal [8] and [9].
- Manual activation of external water supply (for core cooling purposes) [10].
- Containment flooding/Containment water filling [11].
- Manual depressurization of containment [12].
- Manual isolation of leak [14].
- Heavy load drop [19]
- HRA methods or treatment of action without procedures [20]
- HRA method for Hazards [21]
- LOCA during shutdown [22]

In addition, an assessment has been performed comparing the treatment of pre initiators, ref [13]. This comparison has been performed in a more general way, because the number of modelled pre initiators often is very large and since they are rarely analysed in detail.

The evaluation guide described in section III is used as a starting point for the comparison together with the HRA documentation. Where requested information is not found in the HRA, there is a possibility to supplement with information from other sources.

Some operator actions have been assessed further during plant visits, where opportunity has been given to verify or add information at meetings with plant personnel. The initial comparison using the evaluation guide is proven to be an effective method to prepare for these meeting. In addition, the plant visits have involved a walk-through of the locations in the plant, where parts of the actions to be assessed are executed.

VI. FINDINGS FROM ASSESSMENTS OF OPERATOR ACTIONS

The assessments resulted in several interesting findings. For further details on the findings see [28].The findings discussed in detail in the summary report are:

Findings related to actual plant aspects.

- Manual actuation of reactor protection system permission
- Automatic start of residual heat removal function
- Pressure limitations for residual heat removal function
- Indications
- Procedures
- Staffing during critical work
- Conflict of interest
- Safety philosophy
- A new procedure

Findings related to HRA methods and their application.

- HEP assessment
- Level of detail
- Performance shaping factors
- Long term scenarios
- HRA method
- Modelling conflict of interests
- Use of historical data
- Modelling of hazard consequence limitation
- Approaches to model actions without procedures
- Initiating events and recoveries

Findings related to PSA applications, which directly or indirectly affect the HRA.

- Modelling of recoveries
- Modelled scenarios
- Modelling of pre initiators
- Level 2 PSA modelling

VII. DESIRABLE ATTRIBUTES OF CURRENT HRA METHODOLOGIES

During phase 2 and 3 EXAM-HRA has contributed to the OECD NEA CSNI WGRisk/WGHOF project to identify and define desirable attributes of HRA methods. The project included activities to:

- Derive a set of attributes against which HRA methods can be evaluated
- Conduct an evaluation of HRA methods used in OECD member countries for nuclear risk assessment
- Provide a basis from which HRA users can select appropriate HRA methods for different HRA applications

The report [26] presents the results of the project including the evaluation of a range of HRA methods used in OECD member states against the attributes.

VIII. REASSESSMENT AND FINDINGS

The result of the reassessment suggests that the methodologies to some extent are combined. This means including additional performance shaping factors compared to Swain, as well as performing a more explicit analysis of the action steps. Task analysis should at least qualitatively check for each step, whether there is personal redundancy, and whether there are recovery factors, that permit corrections of steps which originally may have failed. It appears to be justified to use simplified techniques for quantification or even to neglect action steps in some circumstances, provided a sufficient level of recovery factors and that personal redundancy can be demonstrated. However, when performing a more detailed analysis it is important not to lose the overall picture and always keeping in mind the context in which the action is to be performed.

IX. STATE-OF-THE-ART OF HUMAN RELIABILITY ANALYSIS

This State-of-the-Art review of Human Reliability Analysis, ref [24], provides an overview of relevant guidelines, evaluations and standards concerning HRA for nuclear power plants and summarizes their key elements. The report present summarizes of the considered HRA reference documents. An overview of recent and ongoing international activities in the field is also included.

X. PRACTICAL GUIDE TO HRA

The final reporting of the EXAM-HRA project provides an overview of the assessments done by developing a “Guidance on methods” document. This is presented in the form of a Practical Guide to HRA [27] based on experience from the survey, evaluations in case studies and reassessments performed within this project.

The guide covers a need for a short and practical guide to HRA. The focus is on guidance for application of HRA methods. The practical guide shall support a PSA practitioner with recommendations on how to navigate through the HRA jungle by presenting a report easy to read with clearly expressed opinions.

The guide provides an overview of method and guidance available in literature and discusses considerations to take into account for the HRA attributes involved in a HRA application. Practical recommendations are presented together with actual observations from the case studies for each attribute to support the recommendations.

This guide presents no new methods or any new comparison of methods. The practical guide starts with an outlook on available methods and guidance, to give reference to what can be seen as good practice when performing an HRA. The practical guidance is presented by using the attributes ("key words") presented in the Table 1 to represent the HRA process.

Table 1 The *attributes* ("*key words*") to represent the HRA process.

<table>
<tr><th colspan="3">HFE Definition</th><th rowspan="2">Quantification</th><th rowspan="2">V&V</th></tr>
<tr><th>Selection</th><th>Data Collection</th><th>Qualitative Analysis</th></tr>
<tr><td rowspan="3">Identification</td><td rowspan="3">Plant Organization/ Management</td><td rowspan="4">Task Analysis</td><td>Methodology</td><td rowspan="2">Reasonableness</td></tr>
<tr><td>PSF Calculation</td></tr>
<tr><td>Dependencies</td><td rowspan="3">Transparency</td></tr>
<tr><td rowspan="3">Screening</td><td rowspan="3">Task Specific Information</td><td>Uncertainties</td></tr>
<tr><td rowspan="4">PSF Assessment</td><td>Recoveries</td></tr>
<tr><td>Minimum Believable Results</td><td rowspan="3">Adequacy</td></tr>
<tr><td rowspan="2">Errors of Commission</td><td rowspan="2">Task Context</td><td>Actions without Procedures</td></tr>
<tr><td>HRA for Hazards</td></tr>
<tr><th colspan="5">Documentation</th></tr>
<tr><th colspan="5">HRA Team</th></tr>
</table>

Each chapter discusses each attribute in a separate section and each section discusses:

- **Consideration**, problem definition stemming from the assessments made of existing applications
- **Recommendations** based on the evaluations, formulated with the objective to reduce variability
- **Observations** from case studies made of existing applications

XI. CONCLUSIONS

The evaluation format that has been developed within the EXAM-HRA project has been found useful and the assessments of actions performed in the case studies have resulted in findings regarding plant features as well as features of the HRA and PSA applications. Some findings that deserve to be highlighted are:

- Difference in plant feature: In some plants, restoration of residual heat removal function involves manually triggering a low pressure scenario by triggering a reactor protection system permission. This was found to be a complex action, especially in some plants, which should be reflected in the HRA as well as the estimation of the HEP.
- Difference in HRA application: The level of detail varies, both in the HRA documentation and the analysis itself. The assessments have resulted in findings concerning the use of simplified results, which sometimes results in less conservative methods, contradictory to the intention. On the other hand, the more detailed the HEP assessment is, the more conservative the result tends to be. It should consequently be discussed whether it is possible to define an appropriate level of detail in order to achieve a realistic value, which is neither too conservative nor not conservative enough.
- Difference in PSA application: In some PSAs, no manual actions are modelled as part of the flooding scenarios. In others, significant operator actions are identified, which are credited in flooding isolation in order to avoid degradation of safety components.

The final reporting of the EXAM-HRA project provides an overview of the assessments done by developing a “Guidance on methods” document. This is presented in the form of a Practical Guide to HRA [27].

The human failure events (HFE) presented in the survey report and application framework has been used to develop a “Guidance on scope” document presented in the Application Guide [25].

The recommendations presented in the Practical Guide are based on the experience gained from the case studies and the findings regarding plant features as well as features of the HRA and PSA applications. The recommendations made for the HRA process are supported by specific observations from the case studies.

The recommendation presented is structured according to a set of HRA "key words" that represents important steps in the HRA process. The key words have been chosen by the EXAM-HRA project team of HRA/PSA practitioners/experts and are supported by our outlook on available methods and a summary of international guidance related to HRA. Practical guidance and recommendations are provided for all areas the in ASME PRA standard.
The project format provides great opportunities to learn about important aspects influencing the HRA applications, such as:

- Actual plant differences
- HRA aspects
- PSA aspects

The work has included involvement of plant staff in the EXAM-HRA working group itself as well as plant staff during plant visits when developing the case studies and the guides. A lot of experience has been gathered on ”how to do” or ”what to do”.

Open issues discussed in the working group that may call on further developments are:

- Conflict of interest: In several of the case studies it has been noted that operator actions may have conflict of interest (COI) as an element that need to be assessed in the HRA. If the COI element is not taken into account the quantified HEP value may be optimistic.
- The balance between diagnosis/decision/implementation modelling in terms of level of detail and resources.
- Error of commission: Errors of commission (EOC) means the potential to make a situation more serious. EOC are strongly influenced by the way the alarm patterns and instruments of different scenarios may be nearly similar. The control room team will then diagnose the wrong initiating event, and decide for the wrong actions.
- The Nordic industry should benefit from a better documentation of the Enhanced Bayesian THERP methodology.

If the practical guide will fulfil its purpose is dependent on its use and application. The main future benefits are expected to:

- strengthen the HRA process in the development or updating of the plant specific PSAs
- support the HRA practitioners in their dialog and interaction with PSA experts and human factor specialists
- support the assessment of available applications when used as a ”sanity check” of the results derived.

This overview and the practical recommendations on good practice shall support the assessment of plant specific aspects in HRA and ultimately improve the plant risk.

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Abbreviations

ATWS Anticipated Transient without Scram
HEP Human Error Probability
HRA Human Reliability Analysis
MCR Main Control Room
PSA Probabilistic Safety Assessment
PSF Performance Shaping Factor
RCPB Reactor Coolant Pressure Boundary
RHR Residual Heat Removal
RPV Reactor Pressure Vessel
SAMG Severe Accident Management Guidelines