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Evaluation of Existing Applications and Guidance on Methods for HRA – EXAM-HRA - Phase 3a Summary Report

Kent Bladh[1], Jörgen Frohm[1], Tobias Iseland[1]
Anders Karlsson[2]
Günter Becker[3]
Lasse Tunturivuori[4]
Markus Porthin[5]
Anders Olsson[6]
Jörg Böhm[7]
Gunnar Johanson[8], Sandra Jonsson[8]

[1]Vattenfall R&D, Sweden
[2]Forsmark, Sweden
[3]RISA, Germany
[4]TVO, Finland
[5]VTT, Finland
[6]Scandpower, Sweden
[7]Mühleberg, Switzerland
[8]ES-konsult, Sweden

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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 action 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 state of the art HRA for purposes of PSA, to ensure that plant specific properties are properly taken into consideration in the analysis. This shall also provide means to improve the experience feedback on plant features based on HRA and PSA results. The project is performed in several 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 survey provides an overview of performed HRA applications, including app. 420 operator actions from six PSA studies, and constitutes basis for the selection of scenarios and actions for assessment in the upcoming phases. The case studies resulted in observations that allow for improvements of both plant features as well as the HRA itself. Additional assessments were performed on a number of operator actions in order to generate more comprehensive observations regarding both the plant features and HRA applications.

The evaluation format that has been developed within the EXAM-HRA project have 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 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 can be used in a final stage of the project to define good practice and provide guidance for inclusion of plant specific aspects in HRA applications in the context of PSA.

Key words

Human reliability analysis, probabilistic safety analysis, operator actions

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NKS Secretariat
P.O. Box 49
DK - 4000 Roskilde, Denmark
Phone +45 4677 4041
www.nks.org
e-mail nks@nks.org

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

Phase 3a Summary Report

Final Report from the NKS-R EXAM-HRA activity

(Contract: AFT/NKS-R(13)110/10)

Kent Bladh, Jörgen Frohm, Tobias Iseland[1]

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Abbreviations

ATWS	Anticipated Transient without Scram
HEP	Human Error Probability
HRA	Human Reliability Analysis
LOOP	Loss of Offsite Power
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

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Summary

Are there actual differences in plant features that explain why human reliability analysis (HRA) results differ between plants for similar action 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 state of the art HRA for purposes of PSA, to ensure that plant specific properties are properly taken into consideration in the analysis. This shall also provide means to improve the experience feedback on plant features based on HRA and PSA results. The project is performed in several 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 survey provides an overview of performed HRA applications, including app. 420 operator actions from six PSA studies, and constitutes basis for the selection of scenarios and actions for assessment in the upcoming phases. The case studies resulted in observations that allow for improvements of both plant features as well as the HRA itself. Additional assessments were performed on a number of operator actions in order to generate more comprehensive observations regarding both the plant features and HRA applications.

The evaluation format that has been developed within the EXAM-HRA project have 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 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 can be used in a final stage of the project to define good practice and provide guidance for inclusion of plant specific aspects in HRA applications in the context of PSA.

1. 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. EXAM-HRA is an ongoing Nordic, Swiss and German collaboration project, in which existing HRA applications are assessed and compared in order to identify areas for plant improvement. The main goal of the project is 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.

1.1 Project overview

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

- Survey of operator actions in existing HRAs
- Development of an evaluation guide for assessment and comparison of operator actions
- Assessment of operator actions
- Reassessment of operator actions
- Conclusions for plant improvement
- Guidance for HRA applications

This report provides a summary on the methodology used for the assessments, see sections 2 and 3. Focus thereafter lies on the findings of performed activities, which are presented in sections 5 and 8. Future activities are presented in section 10. A schematic description of the project is shown in Figure 1.

The project consists of the following phases:

- Phase 0: Preliminary survey and project program
- Phase 1: Survey and initial assessment to find discrepancies
- Phase 2: Reassessment and actual plant aspects
- Phase 3: Guidance

This report is part of phase 3 reporting.

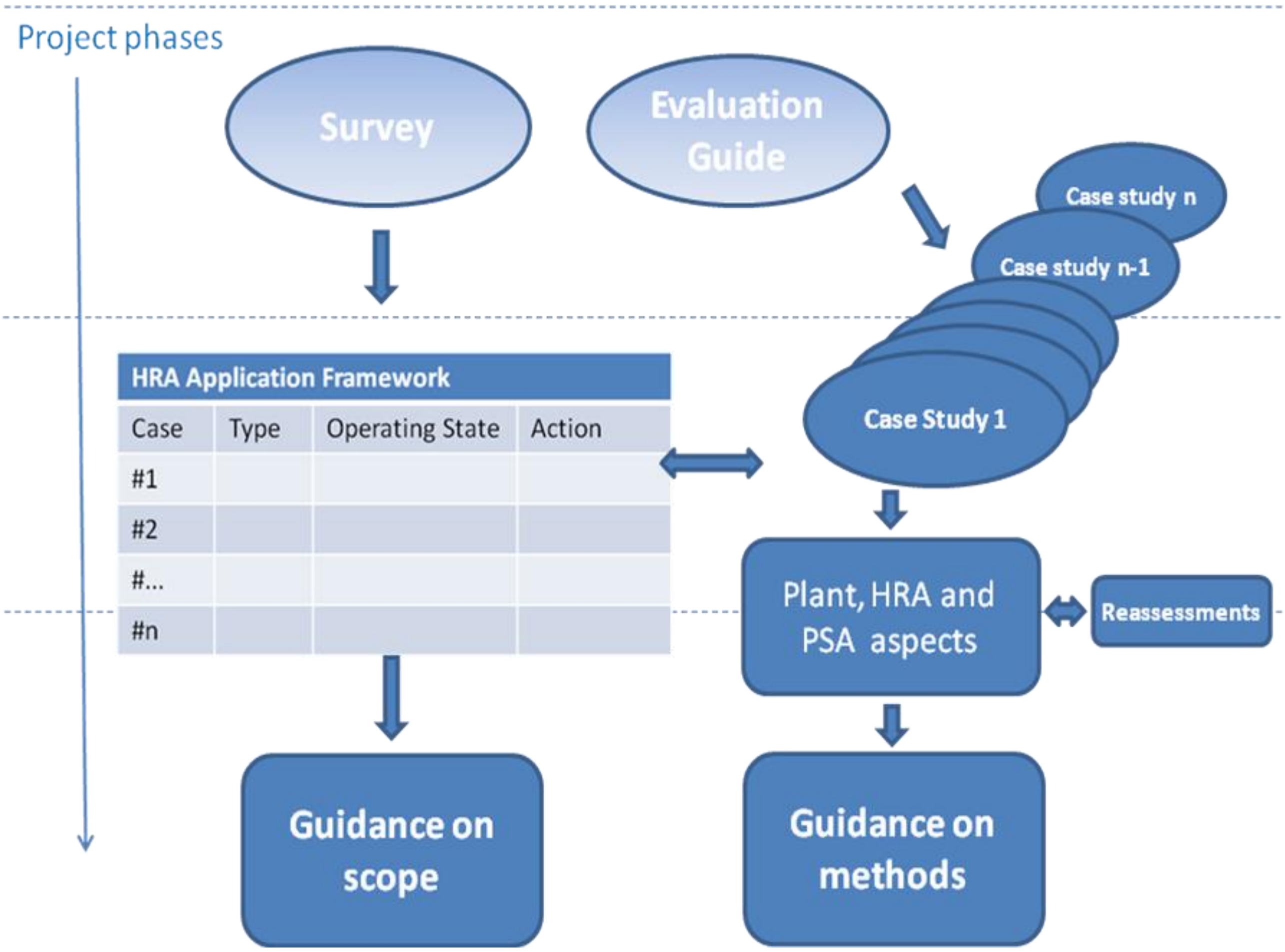

Figure 1. Overview of EXAM-HRA project

1.2 Project Objectives

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 referred to as “plant features” in the following. The guidance developed in the project shall also provide means to improve the experience feedback on plant features based on HRA and PSA results.

1.3 Scope

The investigations performed within the project shall explain why HRA results differ by pointing out specific reasons by identifying and explaining

- HRA differences
- PSA differences and
- plant differences

that have an impact on the outcome of the plant analysis.

Phase 3 will achieve the following:

- Extend the assessments of existing HRA application to a more complete and representative set of cases
- Provide a common basis for methods and guidance for HRA application and assessment
- Improve consistency in in-depth HRA and HEP assessment
- Provide interpretation of important plant features
- Identify areas for improved guidance, work in phase 3
- Identify good operational practices (plant features) based on the analysis of HRA applications

The specific objectives for phase 3 are the following:

- Continue to provide interpretation of important plant features and identify good operational practices (plant features) based on analysis of HRA applications
- On the basis provided by the phase 2 results, (survey, case studies and reassessments) develop guidance on scope of HRA applications and choice of methods for HRA applications.

2. Survey on operator actions in existing HRAs

2.1 Process for Action grouping and Selection

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:

- Actions 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)

Grouping of the actions based on specific safety functions is performed using the IAEA definition on safety functions as presented in [24]. 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 5. 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 8.

2.2 HRA application framework

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.

3. 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.

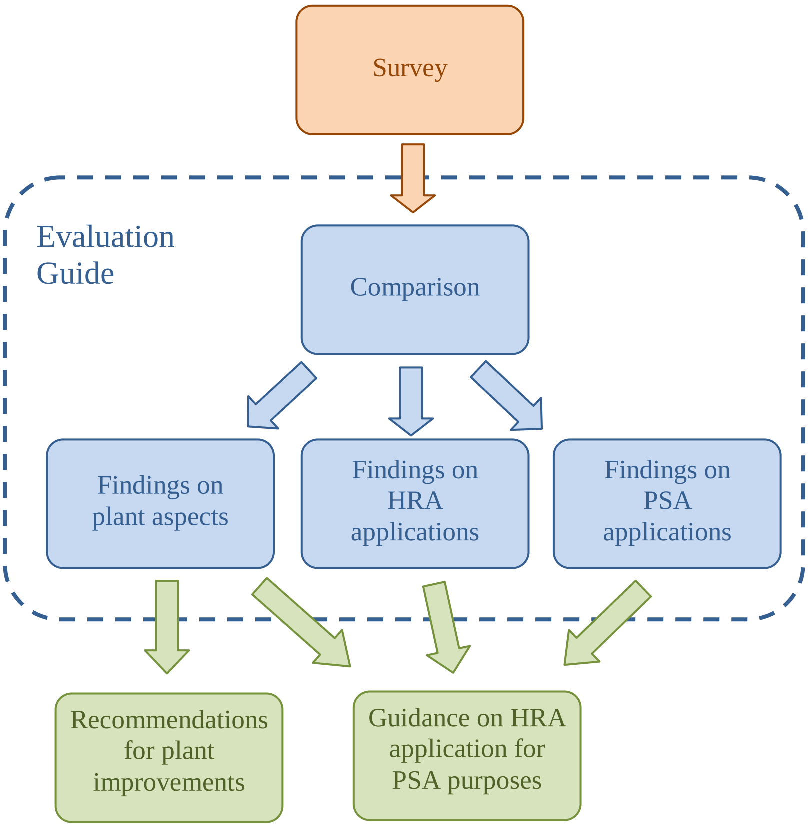

Figure 2. Evaluation guide framework.

A number of considerations for comparison are specified in [4]. These considerations shall be answered when applicable. Additional aspect 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. The insight from the application of the evaluation guide will also be used as input for defining good practice as part of the HRA guidance.

The detailed comparison is built on a number (11) of detailed comparisons as the following example for "Task context 3 Timings" including information, notes (if applicable), comments and conclusions.

Table 1: Task context 3 Timings

TASK CONTEXT		PLANT 1	PLANT 2	PLANT 3	PLANT 4	PLANT 5
3	***Timings***					
3.1	What is the required time for the action? This part can be divided into steps representing different stages of the action if applicable (diagnosis, decision making, execution etc.)					
3.2	What is the available time for the action?					
3.3	Are the timings justified?					
3.4	Are there any considerations of behavioural type done, i.e. skill, rule or knowledge based					
Notes: 1)						
Comments: A)						
Conclusions: I)						

The scenario assessment and the HEP assessment shall be considered for determining significant discrepancies in plant features. Hence both hardware related discrepancies and discrepancies related to PSFs shall be used in order to find strong and weak examples of plant features.

Observed differences shall be explained. The impact stemming from actual plant features shall be assessed at this stage, including an assessment of its validity.

4. Application guide

The application guide [22] is intended to improve the consistency in in-depth HRA and HEP assessment by providing guidance on scope of HRA applications in a plant specific PSA level 1 or 2. This is done based on the overview generated in the project survey and case studies. Screening criteria's in the form of a check list is used for identification of the rationale for inclusion or exclusion of actions in the PSA models.

4.1.1 HRA application framework

The HRA application framework, i.e. the extended table of candidates cases presented in the phase 2 screening and selection report, has been used here to develop a guidance document on HRA application scope. This is done based on a check list to assess the reasoning for inclusion or exclusion of actions in the PSA models. By following the guide means are provided to get an understanding of how the HRA scope has been defined and how analysed operator actions have been chosen.

4.1.2 The screening process

The screening process is in general poorly described across all the PSAs examined in the project.

All participating plants have submitted information regarding operator actions and the scope of HRA applications in their plant specific PSA. An overview of actions is generated in the project survey and case studies and this is summarized by the application context descriptions.

A structure for reasoning when including or excluding an action in the PSA models is used to assess the HRA scope. The screening criteria's used in the different PSAs for identification and the rationale for inclusion or exclusion of actions in the PSA models can be assessed, either as a part of the PSA model development or as a part of a PSA model review. The application scope evaluation shall provide recommendations on details covered in HRA based on an assessment of the reasoning for inclusion or exclusion of actions in the PSA models.

5. Assessment of operator actions

5.1 Introduction to the assessment

The following operator actions were chosen for assessment, based on the survey as described in section 2:

- 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].

The following operator actions have been added during phase 3 and are currently processed:

- Heavy load drop
- HRA methods or treatment of action without procedures
- HRA method for Hazards
- LOCA during shutdown

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 analyzed in detail.

The evaluation guide described in section 3 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.

5.2 Case studies

The EXAM-HRA process for evaluating HRA applications has been tested in example cases were the methods of evaluation are applied to demonstrate the lessons learned by performing the assessments.

The cases are not summarized here. The full assessments are presented in the reference reports. The task context of the cases analyzed is the following:

Case study C.0 – Closing of containment air lock [5]. The function “closing of the containment airlock” becomes necessary in case of a LOCA inside or outside of the containment during shut down periods, when this airlock usually is open. The recirculation system will only work, if this airlock is closed; otherwise, the water inventory is lost from the containment.

Case study C.1 power – Manual restoration of RHR, Power operation, [8]. This comparison deal with the scenario that the plant is in full power operation and after an initiating event a disturbance occurs with the ordinary system for residual heat removal (RHR). The initiating event can be caused by loss of offsite power, which causes the RHR functionality to fail and the plant need to recover from this by taking other RHR systems into operation.

Case study C.1 shutdown – Manual restoration of RHR, Shutdown operation [9]. This comparison deal with the scenario that the plant is in shutdown mode during the early stages of the refuelling outage period where operation of system for residual heat removal (RHR) is required. Two different scenarios can then be considered:

- Reactor Pressure Vessel lid is mounted (RPV closed)
- Reactor Pressure Vessel lid is dismounted (RPV open)

In the scenario an initiating event occurs, possibly loss of offsite power, which causes the RHR functionality to fail and the operators need to recover from this by taking the RHR system back into operation again.

Case study C.2 – Manual activation of external water supply [10]. The types of scenarios that are evaluated here are related to PSA Level 1 but are still somewhat of SAMG (Severe Accident Management) in their nature. The SAMG nature is the sense that is that the operator will try their last option to prevent a core damage to occur by using "un-clean water" (fire water, sea water, river water) and feed it into the RPV/primary system or the condensation pool (and from there it might be transferred to the RPV/primary system) in a feed and bleed sequence. The scenarios described occur during power operation.

Case study C.7/C.13 – Containment water filling [11]. This report contains the comparison analysis of two related human actions: containment flooding and containment water filling. Depending on the plant and the plant PSA model, the actions are related to severe accidents or are in preparation to severe accidents. Containment flooding can be generally described as an action to fill the containment drywell to a certain level. Containment flooding is usually completed in cases where residual heat removal has failed, and severe reactor accident is anticipated. In some plants the flooding action is required before containment water filling. This action can be found in both level 1 and level 2 PSAs. In the level 1 action the aim is to preserve feedwater system (EFW/ECCS) integrity. Containment water filling is a time consuming action which requires multiple actions outside of control room as well as co-operation of different services in the nuclear power plant. For these reasons it can be a difficult to analyze using traditional HRA methods. The purpose of the containment water filling is to cool core after damages and limit radiological releases.

Case study C.10 – Manual depressurisation of containment [12]. Increasing pressure in the containment would cause it to fail resulting in unfiltered release. Pressure- and filtered relief could either be performed manually or automatically depending on design.

Case study A.1/A.2 – Pre initiators [13]. Pre initiators are latent errors and many of them originate from human errors during maintenance work. Maintenance personnel, site technicians and/or contractors as well as control room staff are involved in the events that may cause pre initiators.

Case study C.5 – Manual Isolation of leak [14]. In case of leak or break of a service water pipe, the leak must be isolated to keep pumps of the safety system from being flooded. The leak/break position must be identified and thereafter, the leak/break must be isolated from incoming water by switching off pumps and closing valves.

Reassessment – Comparison of models and analysis methods [15]. In order to obtain a comparison of methods, which is not influenced by differences in the tasks or specific characteristics of the plants, information has been collected which allow applying the German variant of HRA method and the Nordic variants to the same task based on identical information.

The following cases have been added during phase 3 and are currently processed:

Case study C.16 - Heavy load drop. Apart from RPV head drop, there are a number of other heavy load drops considered; drop of containment dome, drop of steam drier and drop of core shroud head with steam separator.

Case study C.14 – HRA methods or treatment of action without procedures. There may be recovery actions which are known by the plant staff but which have not been specified in the emergency procedures or other procedures.

Case study C.15 – HRA method for Hazards. In many cases the method that has been used for HRA in a PSA is chosen from the need for internal events PSA, e.g. transients, pipe breaks, etc. When the PSA is extended to also include other types of hazards (internal fire & flood, external events such as earthquake, severe weather (hot/cold/storm/tornado etc), the already existing operator actions may have to be re-evaluated.

Case study C.13 – LOCA during shutdown. Removing a control rod can cause a leak with an area of 49 cm2 in the reactor bottom. This work is only performed, when the RPV is completely filled up to the level of the fuel element storage, as it is required for a fuel element change. Should such leak occur, there are procedures to over-feed the leak using low pressure pumps.

5.3 Plant visits

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.

5.3.1 Experience from plant visits

Applying the evaluation guide was concluded to be a good way to prepare for the plant visits as it gives the working group a good insight in both scenario and action context.

One insight from the plant visits was that more of the time spent talking to the plant staff should be invested in discussing the diagnosis and decision making. This is especially importing considering that many of the analyses focus only or mainly on the diagnosis part when determining the HEP.

The simulator visit was positive since it provided good understanding in how the actions were performed. However, the action was demonstrated by an instructor, which might result in less information than if it had been demonstrated by the persons who actually performed the actions in the plant.

Example of issues considered during plant visits:

- Is it possible to draw any conclusions about the control room from the observations made? MMI, manning, staff etc?
- Is it possible to draw any conclusions about plant differences (differences in local actions)?
- What is most important, diagnosis or action?
- The assessments cannot just scratch on the surface but must rather be quite detailed. What information and treatment of information is necessary to draw valid conclusions?
- It must be ensured that the same data are collected from two different plant visits in order to be able to perform a proper analysis.
- What kinds of people are of interest to talk to during our plant visits?
- Is it needed to perform more plant visits to have a solid basis for guidance? - This is an important part of the results from phase 2 along with actual finding from the comparison.
- How can we use all the collected data
    - Existing analyses, for preparation
    - New information, about plant, diagrams, procedures, PSA, diagnosis, decision.
    - Reassessments (including the use of other methods)
    - Importance measures

5.3.2 Seminaries in phase 3

Guidance of methods has been discussed during a seminar workshop [23] where opportunity has been given to continue the development of guidance on scope of HRA applications. Example of issues discussed during the workshop:

- With practical guidance issues on:
    - Recommendation on method to use
    - Requirements on HRA method description
    - Requirements on the HRA analyst
    - Requirements on how to document HRA application (including use of software)
- Level of detail
- Requirements on how to document HRA
- Review or comparison against international guidance documents
- One combined guidance from EXAM-HRA, include Application guide
- What is the aim of HRA
- A basic check list, to do list

The work in phase 3b will continue the development of guidance on scope of HRA applications and also develop guidance on methods in the form of a practical guide to HRA, e.g. on choice of methods for HRA applications, team organisation, documentation, etc.

6. Findings from assessments of operator actions

6.1 Findings related to plant specific aspects

The assessments resulted in several interesting findings. This section presents a selection of findings related to actual plant aspects.

6.1.1 Manual actuation of reactor protection system permission

In the case study involving manual restoration of residual heat removal, one possible action at some of the participating plants involves simulating a low pressure scenario by manually triggering a reactor protection system permission. During the plant visit, it was revealed that this action was not performed in the main control room (MCR), but in a relay room adjacent to the MCR. In addition, the execution for the actuation differed between the plants. It is the project team's belief that due to the design of the relay cabinets (structure and interlocks), the actuation is more straightforward and consequently should have a higher likelihood for success in one plant compared to another. This difference in plant design would have been difficult to discover without the plant visits, stressing their importance for the outcome of the EXAM-HRA project.

6.1.2 Automatic start of residual heat removal function

In one of the plants, automatic restoration of residual heat removal using an independent emergency power supply is possible during power operation only. The independent emergency system also includes reactor protection functions as well as other critical supporting functions, which are essential to reach a safe state. Consequently, no operator action is required to restore the residual heat removal functionality. On the other hand, there is no automatic start of the residual heat removal function during shut down for this plant, as this part of the protection system is detached during shut down. For other plants automatic start will be part of the diesel sequence also during shutdown.

6.1.3 Pressure limitations for residual heat removal function

In one plant, there is a recovery action involving cooling via residual heat removal system heat exchangers, which can be used at full reactor pressure. In other plants the heat exchangers have limitations with regards to pressure controlled by protection logics, leaving other options for residual heat removal at high pressures which may be more difficult for the operator to execute.

6.1.4 Indications

One finding from the application of the evaluation guide regarding indications is that the plants in some cases differ in how plant conditions are presented to the operator. In order to diagnose the loss of residual heat removal, the operators at one plant face the indication "malfunctioning of shut down cooling" whereas operators at another plant must make the diagnosis based on information regarding high temperature in the condensation pool and failed or limited function of the containment vessel spray system. This difference in indication might influence the failure probability for diagnosis. In general, function based information is preferable to symptom based information for increasing the likelihood for operator success. This observation can be worth some further thoughts with regard to what can be made from a plant perspective in order to aid the operators to the make the right decision, especially if there is a short time frame for the operators to diagnose, decide and then act. Considering that the emergency operating procedures in several cases also are symptom based it can be discussed to what extent they aid the operators in their decision when time is a critical factor.

6.1.5 Procedures

In order to simplify actions performed outside the MCR, some plants have included photographs in their operating procedures for actions which are seldom performed or trained. This will assist the operator to efficiently locate valves, increasing the probability that the action will be successful.

6.1.6 Staffing during critical work

At one of the plants the operating principle involves a dedicated person, trained to close the containment air lock in case of LOCA inside containment, supervising the air lock during critical stages maintenance work. This was identified as a good practice and might be worth implementing also in other plants.

6.1.7 Conflict of interest

In many plants there are actions modelled which involve conflict of interests. One example is the case of closing containment air lock, where verification that no personnel are left in the containment at closure will influence the action. Another example is the manual activation of external water supply to the reactor coolant pressure boundary (RCPB) or the condensation pool, which would cause severe damage to the plant. However, if external water supply is not connected, a possible consequence is radioactive release. In these cases, the probability of failure due to delayed decision making or execution increases. Clearly documented responsibilities regarding decision making as well as procedures explaining crucial precautionary measures, leaving out unnecessary measures, are likely to increase the probability of a successful action. A discussion on modelling of conflict of interest is found in section 6.2.6.

6.1.8 Safety philosophy

The assessment of the manual action involving containment venting revealed a difference regarding the safety philosophy of the plant. In some plants, the manual actions can be seen as a redundancy to automatic venting involving opening of a rupture disc. In these cases there is an option of filtered venting of the containment that should be used in specific accident scenarios, which are not part of the design basis. The venting is performed to maintain containment integrity and avoid radioactive release. The procedures allows for (or encourage) manual venting at certain containment pressures. In other plants, filtered venting of the containment is manual only and maintaining the containment barrier is highly prioritised. Containment isolation is part of the originally licensed safety concept which cannot easily be deviated from. In this case there is no right or wrong concerning strategy, but it is merely a question of prioritising. In the first case, the risk of minor not necessary radioactive release is accepted when compared to the risk of containment rupture. In the second case, containment integrity is prioritised in the short term, avoiding inadvertent automatic opening of release valves. However, this increases the risk of containment rupture at a later stage due to failed manual action.

6.2 Findings related to HRA applications

This section presents findings related to HRA methods and their application.

6.2.1 HEP assessment

Diagnosis and decision making part is of main focus when determining the HEP. However, the assessments revealed that the process for diagnosis and decision making is often scarcely described. For example, in order to properly determine and apply the PSFs, additional information on the following aspects would be of interest:

- Indications that lead in to the correct operating procedure or emergency operating procedure
- Decision hierarchy, i.e. who makes the ultimate decision
- Indications for verification of decision
- Basis for grace times

The assessment also showed that the action part is often ignored in some of the applications as it is assumed that the diagnosis and decision making is the main contributor to the HEP. The results imply however that this assumption should be made more carefully. It would be of interest to investigate if it is possible to determine specific criteria when the post diagnosis part of the task can be safely neglected. Neglecting the steps after diagnosis can strongly simplify the analysis; however, actions involving many steps with little time for recovery may obviously not have a negligible error probability compared to the error probability of the diagnosis part.

Another finding regards the case of feeding external water supply to the RCPB or the condensation pool. The assessment showed that the plant which does not have any conflict of interest related to the action and where the action is considered quite simple, have a higher HEP than other plants where conflict of interest is of importance and where the action is more complicated. This could be due to several reasons, one possible reason is that the analyses have been performed on different levels of detail, see section 6.2.2.

6.2.2 Level of detail

The level of detail in the HRAs differs widely, both within and between the PSAs. In many cases it is therefore difficult to draw any conclusion based on the HRA information alone. It is obvious that the HRA only provides as much information that is needed dependent on method, which is a limitation since it makes it more difficult to use the HRA for other purposes than for estimating the HEP value. However, by performing a more detailed HRA, the information can also be used for operating and maintenance purposes, increasing the understanding and highlighting the importance of specific actions and their context. The HRA can then reveal potential for improvement rather than just acting as an analysis tool.

Another finding from the assessments is that the simplified HRA applications sometimes give less conservative results than the more detailed applications. This is of importance since one main justification for using simplified methods is that it would result in conservative results. This finding could be due to a number of reasons. One reason is related to the assumption not to include the action part in the assessment, another to how the performance shaping factors are interpreted. However, it could also be that the methods used, which are often applied in a general manner, are in fact not suitable for a specific case.

The issue of need for questioning the method validity indeed applies for both simplified and more detailed methods. In fact, more detailed methods tend to give more conservative, not necessarily more accurate, results. This contradicts the intentions of ensuring more conservative results by using simplified methods. Consequently, the use and application of methods do have a potential impact on the results, regardless of on which level of detail it is performed.

6.2.3 Performance shaping factors

There are some differences in how PSFs are incorporated in the different HRAs. In some studies, performance shaping factors are used as calibration factors to adjust the HEP, which is primarily estimated based on available time for diagnosis and decision making. Also, the different studies included different PSFs. Some studies use the PSFs defined by Swain [25], whereas other studies have extended the PSFs and also include factors such as complexity and coordination of task. The use of additional performance shaping factors does give the potential of performing a more accurate estimation of the HEP. However, if the performance shaping factors are not given the correct value or is being misinterpreted, there is instead a risk of the HEP becoming more inaccurate. Consequently, performance shaping factors can increase the quality of the HEP estimation although, in order for it to be achieved, a thorough task description is a prerequisite.

Another issue related to the PSFs is that they are mainly defined having the diagnosis and decision making process in mind. It could however be occasions where there is a request to interpret PSFs also for the execution, although for this the existing PSFs are not suited. Consequently, there is a need for development of PSFs also for the execution of the action, especially considering the finding that the execution part of the analysis often should be paid more attention.

In some approaches the performance shaping factors have a range of 0,2 … 5. This is used as a multiplier on the base HEP. This means that the PSFs has the same effect on the total HEP. The guidance to use the performance shaping factors gives a connection between each PSF weight and a short qualitative description what that weight should mean in terms of the scenario. Between the Nordic plants severe scenarios might have a total similar effect of PSFs, but the individual PSFs have differences. Especially ‘stress’ PSF might be difficult to evaluate. It can be noted, however, that the individual values of the PSFs do not matter from HEP point of view, as long as the composite effect of the PSFs is roughly correct.

Extensive guidance for assessing PSFs could improve the consistency of the results, but also decrease freedom of expert opinions. Further study would be required to evaluate the whole PSF framework:

- The set of PSFs used
- Definitions of PSFs
- Guidance to evaluate PSF weights
- PSF weight range (is 0,2 … 5 the correct range? Not all HRA methods agree).

6.2.4 Long term scenarios

In long term scenarios, time correlation curves are not useful for estimating the HEP. Instead limit values are applied, although it is not certain these values are more accurate. Another observation related to long term scenarios is that the effects of crew shift as a possible reason for operator failure should be considered. A positive effect of long time available is of course that it makes it possible for other personnel to assist. A critical reason for the error in such cases could be that some important information is missing for the new crew that may have a negative impact on the error probability, compared to the crew who worked on the problem from the beginning of the scenario. A relevant question in such a case is if the shift of crews is part of normal simulator training for the operators.

The inclusion of recovery in the HRA is also dependent on the mission time. Generally a recovery action should be taken into account if there is additional time during the human failure event to notice an error and correct it. In long term scenarios there is a higher likelihood of having 'extra' time for recovery. However, it was noticed that the Nordic HRA applications are not more likely to include recovery possibilities even for long term actions.

6.2.5 HRA method

THERP is the basis for most assessments, although in some cases screening methods or values are used. Local modifications of THERP are used in some HRAs where e.g. additional PSFs are included. These HRA applications are simplified variants of THERP, and are for the most parts based on a modified version of the THERP time correlation curve. Others methods follow THERP more strictly and incorporate the use of HRA trees for modelling the action steps including recoveries in detail.

Comparability would improve by combining the approaches, which would have the following benefits:

- Objectivity would increase if using as little expert estimate as possible.
- Completeness would increase by performing detailed analysis of steps required, in order to identify steps with no recovery and by assessment of additional PSFs
- Consistency could be increased by including additional and more precise guidance on assessment of PSFs.

HRA studies in Nordic countries, in Swiss and in Germany could benefit by considering these aspects of objectivity and completeness, which is not always common practise. The aspects identified are few, but those which exist are considered significant and worthy to be studied further.

6.2.6 Modelling conflict of interests

A reoccurring finding has been concerning conflict of interest and how this can be modelled in a representative way as many of the cases assessed have an element of conflict of interest. However, this is never explicitly modelled. In some cases, the conflict of interest is implicitly included in the performance shaping factors but the underlying documentation used for the assessment do not give any guidance on how to specifically value conflict of interests. For some scenarios, especially in PSA level 2, conflict of interest is likely to have a considerable contribution to the failure probability and this aspect consequently needs to be well understood and properly incorporated in the HRA. One solution is to explicitly include conflict of interest as a criterion in the guidance for evaluating PSFs.

6.3 Findings related to PSA applications

This section presents findings related to PSA applications, which directly or indirectly affect the HRA.

6.3.1 Modelling of recoveries

In one PSA only, restart of the original residual heat removal function is considered. In the other PSAs, recoveries using alternative residual heat removal functionalities are modelled. Other examples are found where recoveries are explicitly modelled in some case, but not in others.

6.3.2 Modelled scenarios

For the case of activation of external supply, one plant had much less time for diagnosis and completion of task than the others. In this PSA, the most conservative scenario, i.e. anticipated transient without scram (ATWS), is used for calculating the available time for the action. This indicates that there is a difference in how ATWS scenarios are treated in the different PSAs.

The comparison of manual actions to isolate flooding revealed some interesting findings. First of all, flooding scenarios seem to be modelled in a conservative way with regard to operator actions meaning that few, if any, operator actions are credited. The actions which are included are treated in a most simplified way. In addition, there seem to be a difference with regard to the importance of the operator actions. In some PSAs it is stated that certain flooding scenarios might degrade the functionality of safety equipment, whereas in other plants, no significant operator actions have been identified in the flooding scenarios. This finding should be assessed further in order to determine whether this is in fact a modelling issue or if it is a result of actual plant differences.

6.3.3 Modelling of pre initiators

Some plants included in the study do not model pre initiators, i.e. latent failures, in their PSAs. The reasoning behind this is the assumption that testing before start-up prevents pre initiators from occurring. At the other plants, testing is seen as a kind of barrier, used to calculate pre initiator probabilities in the PSA models. It can also be argued that testing, and maintenance, activities can be a cause of latent errors. This difference will have an impact on the PSA results. However, modelling of pre initiators should always be made having in mind the possibility that pre initiator failure probabilities is double counted as they might also be included in the CCF modelling.

6.3.4 Level 2 PSA modelling

For certain severe accident management actions, the differences in chosen PSA methodology have large effects on HRA analysis. While level 1 PSA methodologies are standardised to some degree, a larger variation is found in level 2. One of the examined level 2 PSAs used a dynamic modelling approach, which includes variable timing for human actions. This is different from the static approach in level 1 PSA. The dynamic modelling requires the HRA analysis to provide a distribution for success probability based on time, as the human action can have different amount of time available based on dynamic timing. If dynamic PSA methodologies become more prevalent, HRA methods and guidance should include capabilities to model human actions with variable timing.

7. Desirable attributes of current hra

During phase 2 and 3 has EXAM HRA contributed to this activity.

The report [26] presents the results of a joint OECD NEA CSNI WGRisk/WGHOF project to identify and define desirable attributes of HRA methods, and to evaluate a range of HRA methods used in OECD member states against those attributes.

The study aimed to identify the strengths and weaknesses of commonly used and developed methods to aid those responsible for production of HRAs in selecting appropriate tools for specific HRA applications. The study also aimed to assist regulators when making judgments on the appropriateness of the application of an HRA technique within nuclear-related probabilistic safety assessments.

8. Reassessment and findings

A reassessment is performed on the case involving restoration of residual heat removal, which has included recalculation of the HEP value for one plant using the methodology for another plant. The reassessment can be regarded as a sensitivity analysis of the original analysis as well as the methods used. The basis for the reassessments has been both the assessments described in section 5 and the plant visits. The plant visits have been proven essential in order to perform a proper reassessment as much information regarding work processes, procedures etc. which has not been found in the PSA or HRA documentation has been provided.

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.

9. Conclusions

The evaluation format that has been developed within the EXAM-HRA project have 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. Some findings that deserve to be highlighted are:

- Difference in plant feature: In some plant, 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 methods, 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 aims of the EXAM-HRA project are both to provide guidance for a state of the art HRA for PSA purposes, in order to ensure that plant specific properties are properly taken into account in the HRA and to give insights for potential plant improvements.

Formulating the guidance for a state of the art HRA is part of the upcoming work, which will use existing experiences and insights as a basis. There is a potential for both increases in efficiency and in preciseness of HRA analysis by accounting the lessons learnt from comparison and from plant specific reassessments.

10. Continued Work

Phase 3a and 3b (Oct 2012- Dec 2014) shall maintain and extend the assessments of existing HRA application and continue the analysis to provide interpretation of important plant features and identify good operational practices. Phase 3 shall provide an overview of the assessments done by developing guidance on scope of HRA applications and choice of methods for HRA applications. The second seminar, fall 2014, will focus on the guidance on methods and the choice of methods for HRA applications.

The continued work is defined in a phase 3 project program [17] with reference to the initial project program, taking into account additional aspects based on the phase 1 and 2 results.

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Author(s)	Kent Bladh[1], Jörgen Frohm[1], Tobias Iseland[1], Anders Karlsson[2], Günter Becker[3], Lasse Tunturivuori[4], Markus Porthin[5], Anders Olsson[6], Jörg Böhm[7], Gunnar Johanson[8], Sandra Jonsson[8]
Affiliation(s)	[1]Vattenfall R&D, Sweden [2]Forsmark, Sweden [3]RISA, Germany [4]TVO, Finland [5]VTT, Finland [6]Scandpower, Sweden [7]Mühleberg, Switzerland [8]ES-konsult, Sweden
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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 action 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 state of the art HRA for purposes of PSA, to ensure that plant specific properties are properly taken into consideration in the analysis. This shall also provide means to improve the experience feedback on plant features based on HRA and PSA results. The project is performed in several 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 survey provides an overview of performed HRA applications, including app. 420 operator actions from six PSA studies, and constitutes basis for the selection of scenarios and actions for assessment in the upcoming phases. The case studies resulted in observations that allow for improvements of both plant features as well as the HRA itself. Additional assessments were performed on a number of operator actions in order to generate more comprehensive observations regarding both the plant features and HRA applications.

The evaluation format that has been developed within the EXAM-HRA project have 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 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 can be used in a final stage of the project to define good practice and provide guidance for inclusion of plant specific aspects in HRA applications in the context of PSA.

Key words: Human reliability analysis, probabilistic safety analysis, operator actions

Available on request from the NKS Secretariat, P.O.Box 49, DK-4000 Roskilde, Denmark.
Phone (+45) 4677 4041, e-mail nks@nks.org, www.nks.org