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Non-PSA applications of HRA

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Summary

Human Reliability Analysis (HRA) is a tool for assessing the human contribution to failures, usually as part of a probabilistic safety assessment (PSA). The PSA typically only makes use of the quantitative Human Error Probability (HEP) that is produced by the HRA, meaning that the detailed qualitative analyses that underpin this calculation and the knowledge that is produced in the activity are not utilised outside of the HRA. However, qualitative HRA can provide valuable insights into the individual, workplace and organisational factors that drive human performance and errors, and may be useful for a range of risk-informed applications beyond the PSA.

A questionnaire was carried to how HRA has been used outside PSA and what potential HRA has to widen its scope in the nuclear domain. This questionnaire was distributed to Nordic PSA/HRA organisations. In Finland and Sweden, HRA is used in great majority of cases for PSA purposes only. The lack of broader experience of the area seems to be one reason for that as in the survey, the need for guidance was emphasised. The counterpart for this lack of expertise is the lack of respect towards HRA from the part of organisations which are to utilise the HRA originating results. These forces strengthen each other: without understanding the value of HRA, resources are not distributed to develop HRA and HRA expertise, and without proper resources, less HRA can be done.

A reasonable way to solve this problem would be to strengthen HRA from the inside of the HRA community. That can be done in PSA and non-PSA context. Regarding the usage of HRA in non-PSA purposes, lot of possibilities can be identified. Part of them are realised but a lot can still be done. SAFIR programme provides one possibility to strengthen HRA from various perspectives.

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Abbreviations

Acronym	**Description**
ASEP	Accident Sequence Evaluation Program
ATHEANA	A Technique for Human Event Analysis
CREAM	Cognitive reliability and error analysis method
DISC	Design for Integrated Safety Culture
HCD	Human centered design
HCR	Human cognitive reliability
HCR/ORE	Human Cognitive Reliability/Operator Reliability Experiments Method
HEART	Human error assessment and reduction technique
HEP	Human error probability
HF	Human Factors
HFE	Human failure event *or* Human factors engineering
HRA	Human reliability analysis
HIS	Human-System Interface
ICDE	International Common-cause failure Data Exchange project
IDHEAS	Integrated Decision-Tree Human Event Analysis System
MERMOS	Method d'Evaluation de la Realisation des Missions Operateur pour la Surete (Assessment method for the performance of safety operation)
MMI	Man-machine-interface
NARA	Nuclear action reliability assessment
NASA-TLX	NASA Task Load Index
NPP	Nuclear power plant
PRA	Probabilistic risk analysis
PSA	Probabilistic safety assessment
SHARP	Systematic Human Action Reliability Procedure
SLIM	Success likelihood index method
SPAR-H	Simplified plant analysis risk human reliability assessment
THERP	Technique for human error rate prediction
TRC	Time reliability correlation

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1 Introduction

Human Reliability Analysis (HRA) is a tool for assessing the human contribution to failures, usually as part of a probabilistic safety assessment (PSA). The PSA typically only makes use of the quantitative Human Error Probability (HEP) that is produced by the HRA, meaning that the detailed qualitative analyses that underpin this calculation and the knowledge that is produced in the activity are not utilised outside of the HRA. However, qualitative HRA can provide valuable insights into the individual, workplace and organisational factors that drive human performance and errors, and may be useful for a range of risk-informed applications beyond the PSA.

As an example we consider Human Factors Engineering (HFE) which can be seen as a general application of human factors knowledge to the design and construction of socio-technical systems. In the nuclear sector, the U.S.NRC (2012) Human Factors Engineering Program Review Model NUREG-0711 is the main reference document followed in plant modernisation and new-built projects. NUREG-0711 recognises the "integral" role of HRA in PSA. The standard also clearly states that HRA should form part of the HFE process: "A HRA evaluates the potential for, and mechanisms of human error that might affect plant safety. Thus, it is an essential feature in assuring the HFE program goal of generating a design to minimise personnel errors, support their detection, and ensure recovery capability". In practice, however, HRA is often not linked to the HFE or design process at all, and there is little guidance available to support the analyst in performing HRA in a non-PSA context.

A questionnaire was carried to how HRA has been used outside PSA and what potential HRA has to widen its scope in the nuclear domain. This questionnaire was distributed to Nordic PSA/HRA organisations.

2 Scope and objectives

Scope of the study is restricted in nuclear power plant context, though many applications are equally valid for non-reactor nuclear facilities. The main emphasis is on non-PSA related applications. It is however somewhat ambiguous to divide applications of HRA into PSA vs. non-PSA related ones.

The purpose of this task is to obtain an increased understanding of the challenges of widespread application of HRA in non-PSA contexts at Nordic nuclear power plants and the clarification of the needs for HRA in the various application areas.

3 Overview of human reliability analysis (HRA)

3.1 Objectives and structure of HRA

Human Reliability Analysis (HRA) is intended as a set of analyses addressing human failures to perform safety-relevant tasks, generally when interacting with a technical system. The typical personnel tasks considered are either during normal system operation, or shutdown, or in response to abnormal situations. Also maintenance and test tasks are in the scope of HRA.

The main objectives of HRA are (Hirschberg 2004):

1. To ensure that the key human interactions are systematically identified, analysed and incorporated into the safety analysis in a traceable manner;
2. To quantify the probabilities of their success and failure
3. To provide insights that may improve human performance.

Depending on the scope of the analysis, the identification of measures to reduce the probability of failure, or more generally to improve the performance conditions, may be an explicit goal of the analysis.

The most representative elements of an HRA are:

- Task analysis and human error identification, to characterize how the task is performed and how it may fail (which actions with undesired consequences may be carried out).
- Qualitative analysis of the performance conditions as these may influence possible failure
- Quantification of the failure probability

These three elements are intended to address the three questions above. Depending on the methods used for the analysis, the three elements overlap; also, some iterations are generally required. Complete overviews of the whole HRA process can be found in the literature (e.g. Kirwan 1994, Spurgin 2010, Forester et al. 2007).

3.2 HRA in PSA context

Human reliability analysis (HRA) is an important part of probabilistic safety assessment (PSA). Adequate analysis of human interactions is one of the elements to understand accident sequences and their relative importance to the overall risk.

The basic method for HRA originates from techniques developed for WASH-1400 (U.S.NRC 1975) in the 1970's, which was published in the 1980's as the HRA handbook (Swain & Guttman 1983) including a method called THERP (Technique for human error rate prediction). THERP is the best known so called first generation HRA method and is used as a reference against which other methods are compared. THERP includes most of the features used also in other methods, such as phases of HRA, concepts applied in the structuring of human interactions into quantifiable entities (e.g. diagnosis, actions, tasks, and recoveries), assessment of performance shaping factors affecting the human error probability, etc.

THERP is a rather comprehensive and detailed method, and for practical use simpler versions such as ASEP (Swain 1996), HEART (Williams 1986), SHARP (EPRI 1992) and SPAR-H (Gertman et al. 2005) have been developed.

While 1st generation HRA methods use a simple error taxonomy and a simple error scenario model, several methods — grouped under the name 2nd generation HRA — have been developed on the basis of cognitive psychology. These methods apply more complex assessment of performance shaping factors and the decision making context to identify the conditions for human behaviour. Well known 2nd generation methods are CREAM (Hollnagel 1998), MERMOS (Le Bot et al. 1999), and ATHEANA (U.S.NRC 2000).

In today's PSA projects for NPP, it is common that several methods can be applied for HRA. Depending on the type of human interaction different methods are applied. It has become a praxis to categorise actions as follows (IAEA 1995):

- Category A actions that cause equipment or systems to be unavailable when required post-fault. Called also per-initiator human errors (when limited to erroneous actions)
- Category B actions that either by themselves or in combination with equipment failures lead directly to initiating events/faults. Called also initiator human errors.
- Category C actions occurring post-fault. These can either occur in the performance of safety actions or can be actions that aggravate the fault sequence. Called also post-initiator human errors.

A typical analysis process can have the following stages:

- Definition of the scope for HRA and formation of the HRA team
- Identification and screening
- Qualitative analysis (task analysis)
- Definition of human failure event (HFE[1]) basic events
- Screening quantification
- Detailed analysis of important actions
- Analysis of dependences
- Documentation.

In reality, the analysis process is iterative, and is often based on earlier analyses made for the same NPP or for a reference NPP.

There may be also specific adaptions of the HRA methods when analysing low power and shutdown, fire, flooding, seismic or other types of external events.

3.2.1 Qualitative analysis

For all types of interactions, cat. A, B resp. C, a qualitative analysis precedes the quantitative analysis. Purpose of the qualitative analysis is to identify and define relevant human failure events, and to qualitatively assess the factors affecting the performance. It should be noted that the distinction between qualitative and quantitative analysis steps is not strict, but the analysis flow should be fluent. It is however useful to keep the qualitative analysis separate from the quantification, since the qualitative analysis should be quite generic and it could be rather independent from the quantification model (allowing some choices with the quantitative model).

Qualitative analysis consists of the following steps:

- Information collection, including collection of instructions, interviews of personnel, talk-throughs, walk-throughs, simulator visits, operating experience analysis.
- Screening process, selection of important actions and related human failure events for further analysis. It is important to document which actions have been screened out and on what basis.
- Task analysis where actions are broken down into tasks and performance shaping factors are assessed. As a result, a scenario for the human failure event is obtained.

3.2.2 Quantitative analysis

The purpose of the quantitative analysis is to provide probabilities for human failure events, which are modelled in PSA. The general aim is that the quantification is done transparently and consistently. Transparency can be achieved by a well-documented qualitative analysis so that one-to-one correspondence between factors and scales is seen. The probability model ensures then the consistency. It is however inevitable that subjective judgements must be made.

[1] Acronym "HFE" has two different meanings: a) Human factors engineering, b) Human failure event. In this report, "HFE" mainly refers to "Human factors engineering".

The quantification approach can be different for cat. A, B resp. C. It is common to first apply some straightforward method, which however may provide some variation with respect to performance shaping factors. The methods can be considered to yield screening quantifications, which should be sufficient for most of the cases. For dominating cases, the analyst may consider to make a more detailed analysis.

One important factor of the quantitative methods is the way the time available for actions is taken into account. Time-dependent models include time as an explicit parameter of the model, and such models are applied to post-initiator actions.

Performance shaping factors (PSFs) represent the effect of contextual factors on the probability of human failure. The number and type of PSFs in various methods vary significantly. Examples of PSFs are working conditions, stress level, feedback from process, availability and quality of procedures, time, training and experience. All generally used HRA methods take into account for some PSFs. PSFs are identified in the qualitative analysis phase.

Figure 1 describes a categorisation of HRA methods depending on the characteristics to address task, time or context. HRA methods can also be grouped with respect to the quantification method (expert estimation, PSF-based, data based), whether human performance is viewed holistically or atomically, number of PSF considered, and so on. On the other hand, it is somewhat arbitrary to divide HRA methods into different categories since all methods are based on a mixture of theoretical considerations and common sense judgements, and the methods provide more or less detailed guidelines to make the assessments. For instance, THERP and SPAR-H also include an explicit time-related model.

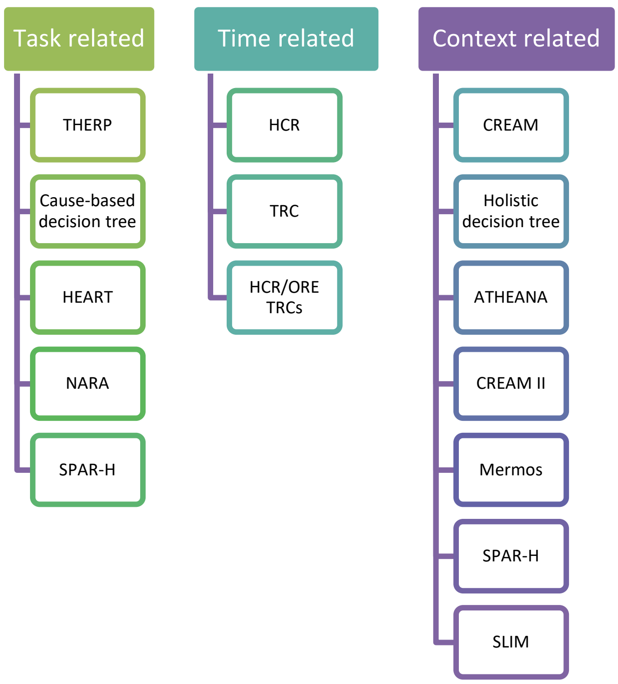

Figure 1. Various HRA models grouped by their characteristics (Spurgin 2010). Acronyms are explained in the beginning of the report.

A number of HRA method reviews and comparisons can be found, e.g., (Forester et al. 2006, Bell & Holroyd 2009, Forester et al. 2013, Bladh et al. 2014, Johanson et al. 2015b, OECD 2015). General requirements, standards and guidance for HRA can be found in (Hirschberg 2004, ASME 2009, IEEE 2010, IEC 2010, ASME 2015, Johanson et al. 2015a, Taylor 2015a, Taylor 2015b).

3.3 HRA applications

There is a broad class of possible HRA applications, and in fact one of the purposes of this report is to clarify these. An obvious group of HRA applications follow the applications of PSA, i.e., when PSA is used to support decision making, it is inevitable that HRA is involved in this process. These "risk-informed" applications include:

- identification of risk significant human failure events
- analysis of importance of improvements in procedures, training, MMI
- analysis of plant modifications
- selection of scenarios for operating training
- test, maintenance and outage planning
- human factors safety review (Vaurio 2009).

Non-PSA context can be assumed to mean any kind of human factors related activities to be considered during various system life cycle phases as listed in Table 1 [IEC 62508]. Examples of non-PSA related applications include

- when designing new procedures, HRA can be used for the identification of areas which need the support of a procedure
- when validating HSIs, the features found vulnerable in human performance should be included in validation, in the form of, e.g., simulator run with which the HSI is validated, and analysed with special care.

Table 1. Human aspects of the system life cycle stages, reproduced from [IEC 62508].

Life cycle phase	Activities
Concept/ Definition	Identify user objectives
	Plan HCD* activities
	Understand user needs
	Define HCD requirements
Design/ Development	Use HF knowledge
	Understand maintenance needs
	Test prototypes with users
	Human oriented design assessment
Realization/ Implementation	Skills training
	Health and safety awareness
	Implement fault management procedures
Operation/ Maintenance	Operation/maintenance records
	Corrective/preventive actions
	Incident reporting
Enhancement	Review in service HF performance
	Process improvements
	Recommendations for design changes
Retirement/ Decommission	HF issues related to disposals, recycling and reuse

* HCD = Human centered design

3.4 HRA knowledge

This chapter summarizes types of knowledge HRA provides. As such "HRA knowledge" is a wide concept which includes

- methodological knowledge, which is generic,
- data type of knowledge which can be originated to specific studies but can be also used in generic purposes, and
- thirdly lessons learnt type of insights.

In addition, knowledge can be classified from the needs point of view. OECD/NEA (2008) addresses the following needs for human performance data in the nuclear industry:

- data on decision-making in abnormal and accident scenarios, which is central to analysing and understanding the risks of scenarios involving errors of commission;
- data related to the ergonomics of computer display-based human-system interfaces;
- data on performance in scenarios with extended time frames, which may be associated with the slower dynamics of Low Power and Shutdown conditions, of passive systems, and of advanced reactors requiring limited actions by the operators in the short term;
- data on human contributions to latent system failures, associated with maintenance, testing, and return-to-service;
- human performance data to explore the importance of safety culture and organisational factors.

3.4.1 HRA concepts

Knowing HRA concepts can be important information for various purposes. Theoretical frameworks of the methods form the basis for the concepts. Theories support systematic reasoning, and can be help, e.g., analysing systems and events or specifying requirements for designs. As described in previous chapters there are some differences in the theories for which reason a distinction is made between 1st and 2nd generation methods and taxonomy of different quantification approaches can be seen as illustrated in Figure 1.

Typically used definitions can be found in HRA guidebooks and PRA standards, such as (Swain 1996, ASME 2009). Human failure event or human error taxonomies applied in HRA should be useful even for non-PSA applications. Example of taxonomies include:

- Type A, B and C human errors, distinguishing time relationship with respect to the initiating event (see ch. 3.2)
- Slips/lapses (action error), mistakes (thinking error), violations (non-compliance)
- Error of omission vs. error of commission. Commission errors can be further classified, e.g. timing error, wrong object error, wrong procedure error, etc.
- Skill-based, rule-based, knowledge based types of decision making (Rasmussen 1983)
- Diagnosis (identification and interpretation), decision making (planning), post-diagnosis action (execution), recovery, if previous steps failed — chronology of steps taken in a problem solving

Most HRA methods apply performance shaping factors (PSF) for assessment of factors or conditions affecting human error probability. Basically, PSF provides means for qualitative and quantitative ranking of human failure events from various aspects. For instance, ASME (2009) lists the following performance shaping factors:

- Quality [type (classroom or simulator) and frequency] of the operator training or experience, including training performed just prior to complex evolutions
- Quality of the written procedures and administrative controls
- Availability of instrumentation needed to take corrective actions

- Degree of clarity of cues/indications
- Human-machine interface
- Time available and time required to complete the response
- Complexity of the required response
- Environment (e.g., lighting, heat, radiation) under which the operator is working
- Accessibility of the equipment requiring manipulation
- Necessity, adequacy, and availability of special tools, parts, clothing, etc.

Depending on the method, different PSF:s and their scales are used in the assessment. Scales can firstly include the question whether certain PSF is present. Secondly, it can be asked whether it influences positively or negatively for the performance.

In a quantitative use, which is essential for PSA applications, PSF:s provides a structure for expert judgements supporting consistency and traceability of assessments. A weakness is the difficulty to validate the correlation between PSF values and HEP and the difficulty to account for the combined effect of PSF:s.

3.4.2 HRA data

Operating experience, pertaining to incidents and deviations in NPP operations possibly affecting safety are reported in the NPPs. The analysis of the reports show what error has been committed and how it has been done. The operating experience reports serve as a tool to learn from past experience, ensuring safety, and the same reports provide also important information to HRA.

Simulator studies typically originate from operator training which uses also simulator runs. During simulations, it is possible to train incidents and accidents in a controlled way, emphasising such aspects in the proceeding of events which require more training. Simulator runs can also be organised to learn how operator perform in some specific situations in general. The way operators perform during these simulated events reveal also what aspects in the operations are the weak points, more prone to operating errors.

Scenario talk-through/walk-through provides information of what operators have in mind or have really done related to the scenario in question. The scenario can be, for example, a simulator run which operator just has performed or some other event. During the talk-through/walk-through the same succession of events is performed but now so that the operator talks aloud or shows not only what (s)he has done but also why such a choice to operate has been made. This type of methodology provides information of the actual operations and the cognitive reasoning behind an erroneous operation or the possible situations where uncertainty or faulty reasoning has taken place, even if the actual operation has been correct.

3.4.3 HRA/PSA-based safety insights

When HRA is part of PSA, results from PSA provide insights on importance of analysed human interactions. This information can be obtained by looking at the risk importance measures of human error related basic events. It should be, however, noted that the PSA model includes uncertainties and simplifications for which reason interpretation of results may require e.g. further sensitivity studies to better assess the risk importance of certain action.

3.5 Human Factors Engineering

Human Factors Engineering (HFE) is the application of human factors knowledge to the design and construction of socio-technical systems. The objective is to ensure that systems are designed in a way that optimises the human contribution to production and minimises potential for design-induced risks to health, personal or process safety or environmental performance. HFE plays a major role in supporting plant safety and providing defence in depth (O'Hara et al. 2012).

HFE program, as expressed in NUREG 0711 (O'Hara et a. 2012), consists of 12 elements which also define the application areas for HFE. The elements can be ordered around the general activities (described also in Figure 3).

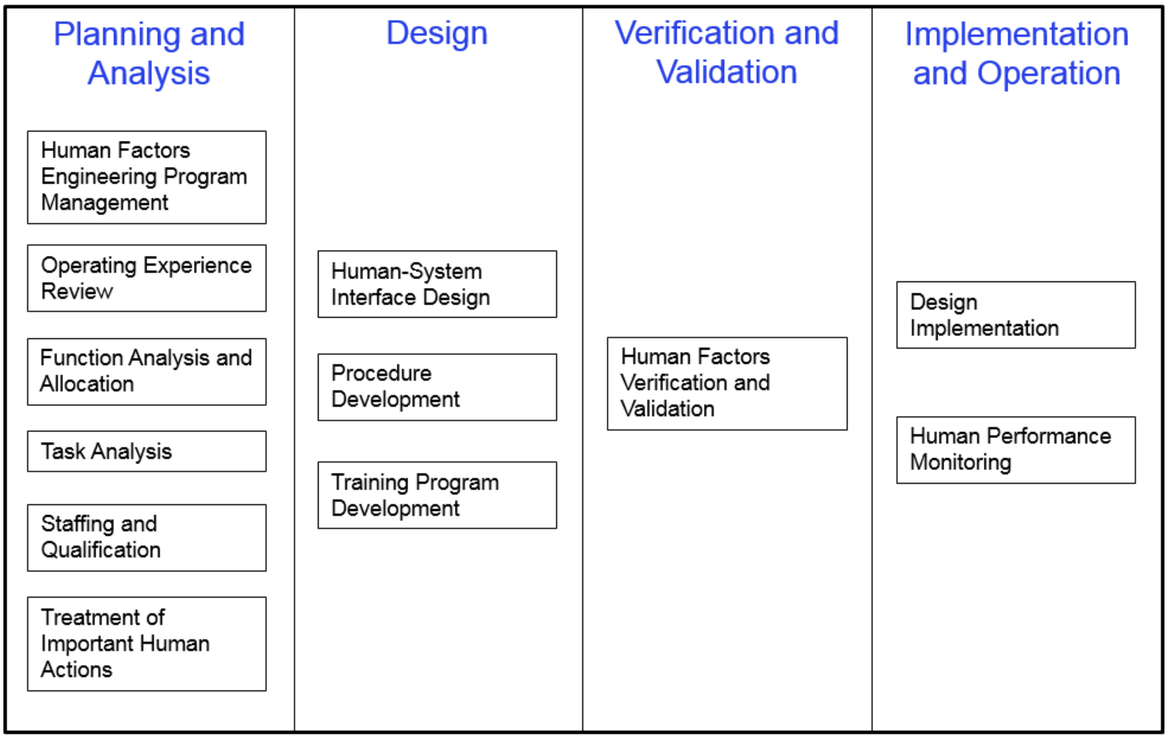

Figure 3. Elements of the HFE program's review model, reproduced from [NUREG 0711 Rev. 3].

The phases cover the life cycle of the NPP, starting from the definition of important human related aspects, taking place before the plant is operational, till the humans perform their tasks in the functioning plant. Whenever such changes take place in the plant which affect human performance, the corresponding element must be renewed as well. For instance, if even part of the HSI is renewed, human factors verification and validation must take place. Thus, the HFE as defined in NUREG-0711 does not, so far, include the activities related specially to decommissioning.

In the NUREG 0711, the specific methods related to each of the activities are not recommended nor described. Instead, only some criteria for the methodology are presented, related to the element in question. The methods used in HFE can be found in scientific literature but in practice, there is a variety to choose from and they are context specific. The methods used, as described in journal articles, can be regarded as candidates to be used in the context in question, approved by the scientific community, and not as recommendations or standards. For instance, O'Connor et al. (2008) used only critical incident technique when identifying the team skills required by nuclear power plant operations personnel. In contrast, Jou et al. (2009) used (i) task completion time, (ii) reaction time, (iii) heart rate and (iv) the questionnaire NASA-TLX (NASA Task Load Index) to measure various types of workload of human-system interface automation in the advanced nuclear power plants. Thus, the variety of available methods and the specific context and goal related to the research study guide (but not dictate) the choice of methodology.

3.6 Safety culture and organizational factors

The concept of 'human error' is easily regarded to refer to errors people perform as individuals. People do their work, however, as members of their work organization. Their tasks originate from the fact they work in a certain role, with certain responsibilities and degrees of freedom to decide on matters related to their work. The roles are, respectively, related to other roles in the form of expected collaboration, coordination or as relationships between superiors and subordinates which coexist in large organisation in many levels, structured by organizational architecture such as departments and branches. Work organization can be regarded as a system with defined interconnections both within and also outside the organization.

Organizational culture is a concept often used to describe shared corporate values that affect and influence members' attitudes and behaviours (Cooper, 2000). Culture is something less openly defined than the evident and documentable organizational structure but it influences on how people do their work and how they act in situations not dictated by their specific responsibilities related to work role.

Especially safety-critical organisations should have the ability to monitor its safety, anticipate possible deviations, react to expected or unexpected perturbations, and learn from weak signals and past incidents (Hollnagel, 2004; Weick & Sutcliffe, 2007). These abilities are the ones describing well-functioning safety culture (Oedewald, Pietikäinen, Reiman, 2009). According to a perspective of safety culture developed in VTT, a model of key organisational dimensions of safety culture is defined.

The cornerstones of safe activities are the appropriate mindset, understanding and organizational systems and structures (Oedewald, Pietikäinen & Reiman, 2011). Regarding mindset, safety should be an important value in the organization, responsibility of the plant safety should be taken by everyone and organization should be mindful in its' practices. Regarding understanding, the organisation should understand the hazards related to the activities, the connection of one's work to plant safety and the systemic nature of safety. Regarding the systems and structure, the organizational systems and structures should create good preconditions to work with good quality. The actual DISC (Design for Integrated Safety Culture) model (see Figure 4) describes the dimensions critical for safety culture six main criteria, which are (1) safety is a genuine value in an organization, which reflects to decision-making and daily activities; (2) hazards and core task requirements are understood thoroughly; (3) safety is understood as complex and systemic phenomenon; (4) responsibility for the safe functioning of the entire system is taken; (5) organization is mindful in its practices; and (6) activities are organized in a meaningful way (the matters in the green area of the Figure 4). These criteria are enabled by the specific organisational functions such as management actions, change management, learning practices, safety communication etc. (the matters in the grey area in the Figure 4).

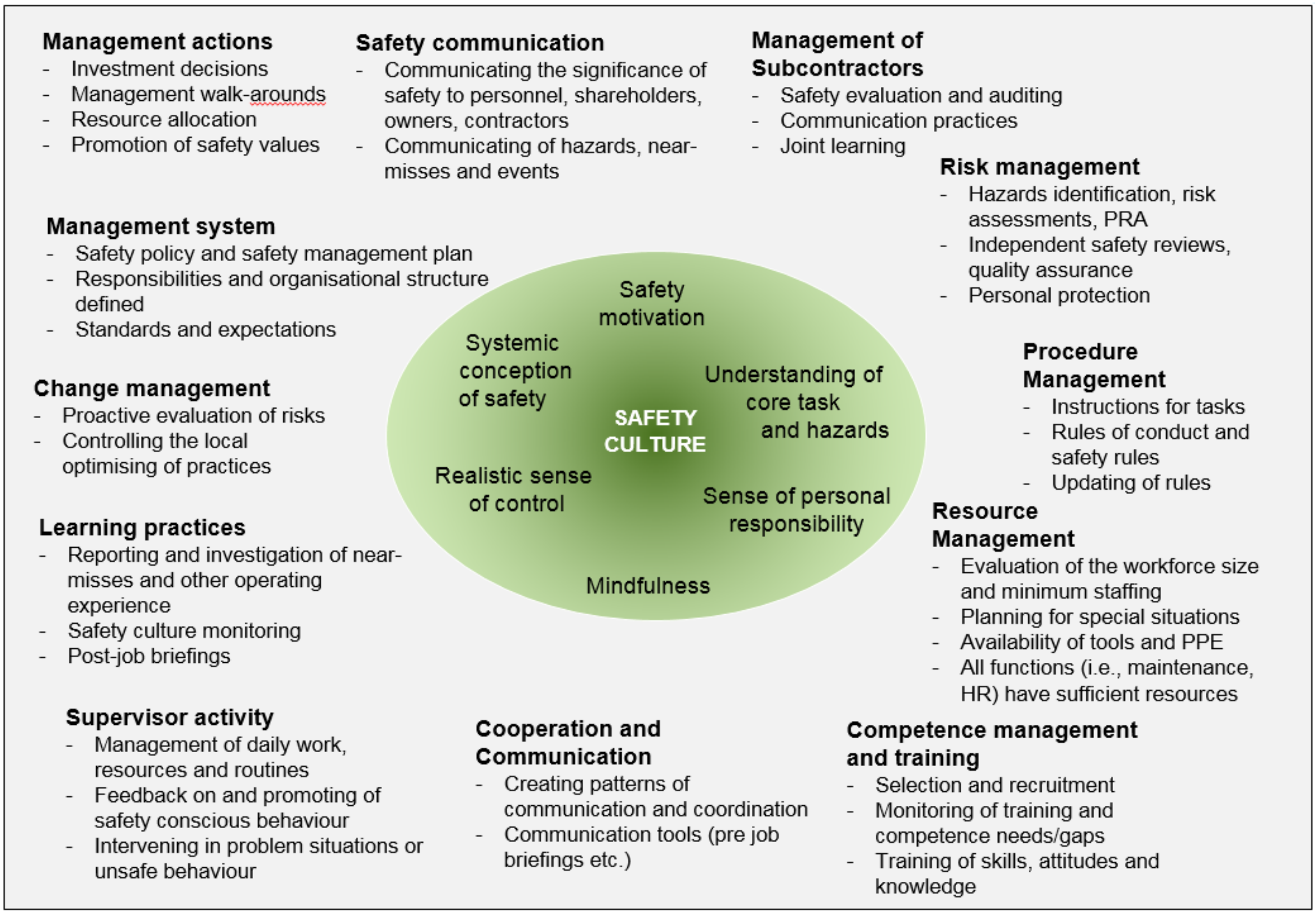

Figure 4. Key dimensions for organizational safety culture, shortened from Oedewald, Pietikäinen & Reiman, 2011.

Individual performance is affected by organizational factors as a whole and, thus, also by the safety culture of that organization. Organisations modify, enable and constrain the work performance and work related activities of an individual - the same person can assume different attitudes and sensitivity to safety related matters, depending on the organisation (s)he works in. Safety culture affects safety related performance which means all behavior related to the safety culture criteria; such performance includes and exceeds, hence, the activities which relate to the tasks defined to the role in question.

4 Survey

Seven organisations replied to the survey, from the total of thirteen organisations the survey was sent to. Four of the responding organisations were utilities (Forsmark, Ringhals, Fortum and TVO), one regulator (STUK) and two consultants (Lloyds Register and ÅF-Consult). Below is a summary of the provided replies. All replies pertain to the nuclear domain unless otherwise stated. For the precise formulation of the survey questions, see Appendix A.

4.1 Experience related questions and the related responses

The first three questions in the survey presume that the respondent has experience of the matter in question. The fourth question in this category is to clarify why this experience has not been gained. Below are the questions and the corresponding, shortened and reorganised replies (some longer replies may be split into parts and responses are ordered to group similar responses together).

1) Has HRA been part of non-PSA activity in your organization, in what way?
   - HRA is primarily used for PSA purposes.
   - HRA assessment has been used to support verification that the reliability goal is met in a plant modification.
   - HRA assessments have been used to evaluate effectiveness of post Fukushima actions.
   - Some cases have been studied with HRA in more detail than has been done in the PSA. However, these studies could have been part of PSA as well.
   - We have been discussing with our company providing training to operators how manual actions as dealt with in PSA could be used in planning training programs.
   - Examples of this are operator training and procedure development.
   - Most HRA work is performed for PSA purposes but we have used HRA insights in a new plant for control room design. (As a consultant company, we also have used HRA for other industries and human error reduction recommendations were important for oil and gas.)
   - HRA has been used as part of analysing operating experience feedback, licensee event report and in plant modernization.

To summarise, HRA seems to be used little in other than PSA context. The provided non-PSA examples could have often been also PSA-examples but for various reasons HRA assessments have not been implemented in PSA. Usually the trend seems to be to use HRA in these other contexts only as exceptionally. One reply indicates that HRA could be used also systematically in non-PSA context (operator training and procedure development) and one respondent reported they have identified that training could benefit from HRA.

2) If HRA was used in a non-PSA context, what were the challenges?
   - No remarkable trouble but as said, HRA is mostly used in PSA context.
   - The way human performance is analysed depend on the application; HRA analyses are not as detailed as the ones performed in HFE.
   - In some recent cases there were no trouble.
   - There are limitations in many current HRA methods, such as focus on quantification to fit PSA needs or lack of sufficient guidelines.
   - When HRA has been used for analysing operating experience feedback, there has been several challenges, the most important ones being the challenge (a) in deciding the level of detail and the boundaries for carrying out HRA; (b) in gathering both objective data and to gather data sufficiently; (c) in the time-consuming nature of many tasks such as gathering the data (interview, questionnaire), assessing the outcome of the data gathering, presenting the results in a comprehensive manner, justifying the outcome of assessment; and (d) in obtaining recognition and acceptance for using HRA in the organisation as people do not see the benefit of HRA and consider it very subjective.

To summarise, respondents did not usually find any specific challenges in using HRA in a non-PSA context, probably mainly because they did not have very much experience about it. In one response it was stated HRA has less detailed analysis methods than the ones used in HFE. One respondent highlighted limitations of HRA methods and lack of appropriate guidelines. One respondent identified several challenges, party related to the amount of work related to HRA and partly related to the negative attitude toward HRA.

3) If HRA was used in a non-PSA context, how successful was it?
   - The usage of HRA was successful in the plant modification example.
   - Use of HRA supported the decision to some changes in instructions.
   - There are always challenges when using HRA in non-PSA context and the results depend on the application. However, HRA can bring new insights and viewpoints. For example, we have used HRA for identifying risk-important scenarios for operator training.
   - We used analyses which were very close to normal PSA and thus, had good routines for that. Consequently, we could make decisions based on HRA.
   - HRA provides good input in the form of quantitative results and can highlight human actions significant from risk perspective and it is also easy to communicate with plant personnel when having HRA findings.
   - With HRA, you can identify the behaviour pattern or acting upon certain perception which most likely contributed to a certain failure, based on data from experience feedback database. Then it is possible to plan corrective measures and minimise that specific risk. With HRA it is possible to enhance the knowledge regarding human error and its consequences in order to operate NPP in a safe manner.

To summarise, respondents described the successfulness of using HRA in a non-PSA context by telling how HRA provided the needed answers to the questions, enabling practical changes; and that HRA provides information related to human actions. Contrasting to usual replies, HRA results were here also found easy to communicate to personnel (the usual response related to the receiving of HRA results is in this survey that due to poor recognition, HRA originating results are not well accepted).

4) In your opinion, why HRA has never been used in a non-PSA context in your company?
   - Due to the challenges, HRA is used less than it would be possible.
   - We don’t have enough people with the HRA competence; furthermore, HRA is still not recognised as a crucial parameter showing how human factors affect the operation of NPP from reliability and safety perspectives; HRA is time consuming and thus also expensive; and finally, lack of knowledge of HRA often leads to the lack of respect of the outcome of HRA

To summarise, only two respondents clarified why HRA has never been used in a non-PSA context in his/her company. One respondent stated the reason to lie in (unspecified) challenges. In the other reply, several reasons were identified: lack of recognition and knowledge about HRA, expensiveness of HRA and the time-consuming quality of HRA.

4.2 Idea and conception related questions and the related responses

The following responses do not require any experience on the matter. Instead, respondents were asked to present their ideas and conceptions. Below are the questions and the corresponding, shortened replies. For the detailed questions, see Appendix A.

5) Where could HRA be used as part of a non-PSA activity?

- Preparation or updating of instructions/procedures (several responses)
- Defining scenarios for training with the simulator, training programme development (several responses)
- Analysis of occurred events, analysis of operating experience (several responses)
- Control room design, for large-scale HMI modernisation, user interface development, user interface validation
- HRA can be used as background information for HF, such as when planning and evaluating corrective measures
- HRA analyses could be used to benefit the following HFE activities: design of tools (to learn what solutions are challenging for operators), procedures and training; planning and conducting HFE validations (to pay attention to the most critical human tasks); and human performance monitoring.
- Plant organisation modernisation, as part of establishing and maintaining adequate safety culture, (and how PSA is involved with maintenance work?)

To summarise, the respondents mainly found the design and development of procedures and instructions as well as operator training as suitable applications for using HRA in a non-PSA activity. Many responses included also control room design and user interface development and validation. As unique replies, the analysis of the reasons for occurring events, background information for HF for instance when planning and evaluating corrective measures, evaluation of external operating experiences, human performance monitoring, plant organisation modernisation and possibly also maintenance work were mentioned.

6) What are the challenges in using HRA in non-PSA context?

- A general challenge is to get contact with relevant context experts who should be interviewed for HRA
- Simulators are owned by KSU [a nuclear power centre for training and simulator training in Sweden] which is a different company, meaning that the communication channels are not self-evident.
- Too little experience and guidance.
- The different view of human performance; the way human performance is analysed differs a lot depending on the application and in HRA the analysis is often less detailed compared to the one performed according to HFE.
- We are an operating organisation without a large development department. HF and HRA/PRA activities are separate both in our organisation and in the national research program.
- From the HFE perspective, HRA data is difficult to transform into information about meaningfulness for design purposes (quantitative HEP:s alone are not meaningful, contextual information and condition understanding are important);

- HRA is difficult to integrate to HF knowledge concerning non-technical skills (operating practise) for achieving appropriate human performance; currently, HRA provides a too simple picture of human performance.
- Budget limitations, lack of HRA method/guideline for non-PSA applications, the acceptance of PSA/HRA findings in risk-informed decision making.
- Time consuming, tight budgets, the lack of agreed-on methodology to assess sparse data.

To summarise, several challenges were identified in using HRA in a non-PSA context, the main challenges being the lack of expertise to conduct HRA, the nature of HRA such as lack of agreed-on methodology or the long duration to conduct HRA, and organisational difficulties such as the budget limitations and lack of acceptance of HRA findings.

7) What are the HFE needs where HRA can contribute?

- Similar answers as to question number 5 (training, procedures, user interfaces)
- Preparation, updating and validation of operating procedures
- Validation of user interfaces, control room design, I&C design
- Coupling between HRA and training could be improved
- Make the management alert regarding HFE and its role in management in an organization, i.e., enhance the present knowledge regarding the HFE
- HRA could benefit from HFE activities, e.g., by providing data and underlying information behind the HEPs
- Data gathering in a systematic way. Preferably, develop a database and share data with other similar organizations in order to increase amount of data and reduce cost regarding development of such a database.
- Benchmarking regarding methodology and definitions of failure.

To summarise, respondents gave similar examples as to the question 5 regarding the HFE needs where HRA can contribute: Preparation, updating and validation of operating procedures; validation of user interfaces, control room design, I&C design; planning of operator training. In addition, data gathering, data sharing, method development and benchmarking were mentioned. It was also stated that HRA could benefit from HFE by providing data and information behind HEPs.

8) How could HRA knowledge (particularly qualitative data) be used in other contexts?

- Similar answers as to question number 5 (training, procedures, user interfaces)
- Research could provide ideas
- Specification of design requirements and comparison of design alternatives
- HRA knowledge could be used when making design decisions concerning user interfaces, procedures, and training. All design decisions should take into account the effect of them on human reliability.
- Regulatory (mandatory) requirement needs to be in place to make use of HRA and PSA insights in the plants. Application guidelines are needed.
- Identification of interesting and important situations and scenarios

To summarise, respondents gave similar examples to how HRA knowledge could be used in other contexts as when asked to describe where HRA could be used without the PSA context (question 5), mentioning training, procedures, and user interfaces. Use of HRA to support decision making related to design, procedures and training were also highlighted by several respondents.

9) What safety related applications could be used for HRA to provide more data (lack of data being the often mentioned weakness of HRA)?
    - If we have data, we do not need HRA. The benefit from HRA is however that it also provides some qualitative insight in for the task.
    - Operating experience should be used when possible
    - Data from simulator runs could be used
    - Collection of data from simulator training is difficult for several reasons. The main objective is to focus on the operators and to give them feedback and hence the instructors have very limited time to record data for HRA. It might still be possible to collect data but it must be well organized and preferably done by many plants together.
    - In other areas, when there are few data exist to analyse, it has been developed by joint project, commitment, database to overcome this obstacle, weakness regarding lack of data, e.g., in the area of fire, pipe rupture. Similar database could be developed to reduce the "weakness" of input data to HRA.
    - The framework by KAERI looks good. "A framework to estimate HEPs from the full-scope simulators of NPPs: unsafe act definition, identification and quantification."
    - There are events/situations which occur repeatedly during an operating year, e.g. certain maintenance activities. Empirical data should be used in those cases. A comparison between HRA assessment and statistical data could be made to judge which one better describes the reality.
    - Event investigations provide data
    - Test and validations provide data
    - To get better understanding of the HRA task, plant walk-down, interview and simulator observation provide good means.
    - It is not sure how the other related plant activities would help us in the understanding of the HRA tasks. Maybe we can get ideas of the safety culture and training level of the plant personnel. However, these factors are not yet covered in the study.
    - Lack of data is also a consequence of the lack of an overview of Human Failure Events covered in different applications. "EXAM HRA Application guide" provides such overview based on its survey. This overview can be used as basis for what data that is needed/missing both in terms of HRA applications but also in terms of data collection, i.e. in some cases to replace HRA applications with operational data.

To summarise, data related issues were seen important but also problematic. Joint effort to collect and analyse data were suggested. It was also claimed that HRA could use more the existing possibilities to gather data.

10) How should HRA be developed (including methods, practices and data)?
    - Evaluations when to use other statistics instead of HRA methods.
    - HRA has many good methods, but data should be used more for HRA purposes
    - To use real data to improve the modelling of dependencies than to improve the modelling of individual actions. Often dependencies are of great importance for the

results and since the probabilities are higher they might be easier to improve/verify with real data.
- Assessment of low bound values which can be justified for HEP of individual person or a group of person
- NRC method IDHEAS sounds very interesting and it might make it possible to make improvements also to other models if one can see that some PSFs are more important than others etc.
- HRA analyses could be more detailed.
- Lessons learnt from EXAM-HRA project should be utilised
- In order to better reflect the complexity of human behaviour, HRA should be developed into taking into account e.g. non-technical skills.
- The qualitative analysis of HRA can be improved in the most HRA studies within PSA. Application guideline would be helpful.
- The qualitative part of the HRA analysis should share the Tasks analysis with other applications, e.g. when handling and ensuring the MTO aspects are taken into account in modernisation projects and new builds.

To summarise, from the viewpoint of how HRA should be developed, HRA presented itself in these responses as something which is not very clear, mainly due to methodological issues. The responses described development needs relating both to the amount and quality of data and the lack of suitable methods or the guideline to use the existing methods. The context in which to use HRA or some other method seems to be unclear as well. Some other methods and projects were mentioned as tools which could be used to support HRA (IDHEAS, EXAM-HRA and utility applications of NUREG-0700 and -0711).

11) What kind of HRA study would be interesting or important to have in SAFIR programme?
- As discussed in question 10 (when to use HRA, when other type of statistics; and what are the low-bound values which can be justified)
- How can HRA be used to plan operator training?
- How can HRA be used in a structured way to improve procedures?
- Assessment of human performance in the context of complex scenarios related to internal and external hazards (confused and conflicting information flow)
- Use of HRA in design phase as well as operation phase. New builds have many new features relevant to HRA.
- Can the modelling of dependencies be verified/made more realistic by use of real data
- How the collaboration between HRA and HFE could be improved. How could the knowledge / conclusions from the HFE be utilized in HRA. An example is data collected in validation of new user interfaces.
- Methods and assessments of root causes for severe accidents (few international cases) as well as for operational disturbances (much more data)
- How can HRA be used in event investigations
- Could HRA inspired methods of modelling human behaviour be used for understanding better the mechanisms of successful operations? Human performance must be approached also from the perspective of successfulness.
- One study could be to review operational plant experience on dependent failures and possibly find defences against such human failure events (HFEs). The work would focus on identifying and understanding dependent pre-initiators HFEs, e.g., human failure mechanisms and its root causes. Pre-initiator HFEs, or “Category A events”,

represent alignment/configuration errors following testing or maintenance, and miscalibration are of particular significance. A large number of event candidates have been identified within the ICDE data. Based on the HRA good practices, NUREG-1792, for identification of pre-initiator human actions, the following analysis activities for pre-initiator HFEs could be included:

- Identify activities/actions resulting in dependent pre-initiator HFEs
- Identify involved PSFs (performance shaping factors) for the specific dependent pre-initiator HFEs

(A study like this has been proposed in the ICDE steering group, no decisions have been made in the steering group when to start such activity and no lead country has been assigned.)

To summarise, respondents consider the following types of HRA related topics would be beneficial to study in SAFIR programme: (1) data (when other type of statistics should be used, what are the low-bound values which can be justified, how to use real data to verify or make more realistic the modelling of dependencies; **(2) methods** (when to use HRA, methods for assessing root causes for severe accidents, methods for studying operational disturbances, how to use HRA in design phase and in operation phase), **(3) how to use HRA related to specific practical objectives** (operator training planning, procedure improvement, assessment of human performance in complex scenarios, how to use HRA in event investigations) and **(4) how to use or develop HRA in broader contexts** (how to improve collaboration between HRA and HFE, how to use HRA to model successful operations or how to find defences against human failure events related to category A).

The results (I) reflect the need of guidelines to use HRA in present or slightly broadened contexts, and (II) show how the usage of HRA could be extended beyond the present usual application areas.

5 Analysis of responses

5.1 HRA related challenges

The starting point to the conceptions related to the HRA related questions seems to be uncertainty of methodology which could or should be used in HRA. Correspondingly, the fact HRA has been used very little in other than PSA context seems to be one of the basic findings of the survey. That is the reason for getting so little experiences of challenges or successfulness of the usage of HRA in these other contexts.

Use of HRA for procedure development, for HMI design and for the planning of training are familiar HRA applications for the respondents. They are mentioned the most frequently when asking about possible applications to use HRA in a non-PSA context. However, only one respondent stated that HRA could be used systematically for these applications and, furthermore, only one respondent reported they have really used HRA for these purposes (but excluding design purposes).

The uncertainty of good HRA methods is reflected also in the responses related to the development needs of HRA. The responses describe development needs related to the amount and quality of data as well as the ones related to methodology - even guidelines seem to be needed. As balancing factors, some methods and projects were mentioned as tools which could be used to support HRA.

Respondents contemplated little the reasons for not using HRA in non-PSA context. The two replies given to this question appear still convincing; in one, it was stated that the situation is as it is "due to challenges", and in another, several insufficiencies were listed lack of HRA (competence, knowledge, respect etc.). It seems to be companies do not invest in HRA to such an extent that the usage of HRA would be possible in other contexts. According to the responses, the reasons for that range from budget limitations to the lack of agreed-on methodology or lack of acceptance of HRA findings. Thus, the reasons may lie in financial matters, in the development needs of HRA itself or in the negative attitudes towards HRA in the nuclear domain. These factors may be connected to each other in a vicious circle; due to negative attitudes, HRA is not financed enough so that its methodology could be developed, and when HRA appears methodologically weak, it is not respected nor considered to provide important data which results in funding difficulties.

5.2 Development needs and ideas

There was a broad area of various proposals for HRA methods development, including better use of data, dependency treatment guidance, assessment of complex scenarios, use of low-bound values, analysis of operating experience data (e.g. ICDE data), success oriented approach to HRA, etc. It can be concluded that due to the inherent nature of HRA and its context (socio-technological risk analysis), HRA will be a topic where continued research is needed. At the same time, it would be important to reach some consensus on acceptable methods.

Lack of data for quantification is seen one of the main problems with HRA. Lack of data leads to reliance on subjective (expert) judgements which are difficult to justify and it is a challenge for having transparent and traceable assessments as generally required for PSA. Improved data collection is seen very important for future success of HRA and its applications.

6 Conclusions

In Finland and Sweden, HRA is used in great majority of cases for PSA purposes only. The lack of broader experience of the area seems to be one reason for that as in the survey, the need for guidance was emphasised. The counterpart for this lack of expertise is the lack of respect towards HRA from the part of organisations which are to utilise the HRA originating results. These forces strengthen each other: without understanding the value of HRA, resources are not distributed to develop HRA and HRA expertise, and without proper resources, less HRA can be done.

A reasonable way to solve this problem would be to strengthen HRA from the inside of the HRA community. That can be done in PSA and non-PSA context. Regarding the usage of HRA in non-PSA purposes, lot of possibilities can be identified. Part of them are realised but a lot can still be done. SAFIR programme provides one possibility to strengthen HRA from various perspectives.

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Appendix A. Questionnaire

Your experiences

1) Has HRA* been part of non-PSA activity** in your organization, in what way?

   * By "HRA" we mean a set of analyses addressing human failures to perform safety-relevant tasks, generally when interacting with a technical system. In particular, we mean type of analyses applied in the context of PSA for nuclear power plants.

   ** By "non-PSA activity" we mean all possible activities where HRA would be used beyond PSA. Examples include plant modifications, training, development of procedures, operating experience analysis. In many cases, it might be difficult to say some activity is a PSA or non-PSA one. You can think that in a non-PSA activity, results from PSA (risk metrics, minimal cut sets, etc.) are not discussed.

   Response:

   If you replied "YES" to 1), please answer to 2) and 3). Otherwise continue from 4) on.

2) If HRA was used in a non-PSA context, what were the challenges in using HRA in a non-PSA context?

   Response:

3) If HRA was used in a non-PSA context, how successful was it? Please, give example(s) if possible

   Response:

4) In your opinion, why HRA has never been used in a non-PSA context in your company?

   Response:

Your ideas and conceptions

5) Where could HRA be used as part of a non-PSA activity?

Response:

6) What are the challenges in using HRA in non-PSA context?

Response:

7) What are the HFE* needs where HRA can contribute?

* By "HFE", we mean application of human factors knowledge to the design and construction of socio-technical systems, such as described in NUREG-0711. HFE includes, for example, operator training and procedure design.

Response:

8) How could HRA knowledge* (particularly qualitative data) be used in other contexts?

* By "HRA knowledge", we mean all kind of assessments made when performing HRA, such as context descriptions, performance shaping factors, time windows, probability estimates, dependency assessments, etc.

Response:

9) Lack of data is often mentioned as a weakness of HRA. Credibility of HRA could be improved by utilising data from other safety related applications*. Do you have any ideas of such opportunities?

* By "other safety related applications", we mean any safety related plant activities which are not directly linked with PSA.

Response:

10) In which manner (in which direction) HRA should be improved/developed, including methods, practices and data?

Response:

11) What do you think would be interesting or important to study in SAFIR programme related to HRA?

Response: