Defining Human Failure Events for Petroleum Risk Analysis

Ronald L. Boring[a*] **and Knut Øien**[b]
[a] Idaho National Laboratory, Idaho Falls, Idaho, USA
[b] SINTEF, Trondheim, Norway

Abstract: In this paper, an identification and description of barriers and human failure events (HFEs) for human reliability analysis (HRA) is performed. The barriers, called target systems, are identified from risk significant accident scenarios represented as defined situations of hazard and accident (DSHAs). This report serves as the foundation for further work to develop petroleum HFEs compatible with the SPAR-H method and intended for reuse in future HRAs.

Keywords: HRA, target systems, human failure events, petroleum, SPAR-H.

---

1. HUMAN ERROR IN THE PETRO-HRA PROJECT

Human reliability analysis (HRA) methods have largely been developed in support of nuclear power control room operations. For example, the original HRA method, a Technique for Human Error Rate Prediction (THERP; Swain and Guttman, 1983), features a set of simplified scenarios that match key actions primarily performed by reactor operators. However, actions taken in a nuclear power plant control room do not in all cases generalize to the types of actions performed elsewhere. As such, it can be challenging to extrapolate these scenarios to other domains like the petroleum industry. Moreover, the data basis for these nuclear centric actions may not match other industries. This mismatch can lead to questions about the non-nuclear validity of the human error probabilities (HEPs) derived from the HRA methods. However, it is important to note that the data in THERP, which has also served as the foundation for many other methods, was originally collected from nuclear weapons assembly work and later generalized to nuclear power. It is therefore reasonable to assume that with careful consideration, existing HRA methods and their underlying quantitative bases could reasonably be extrapolated to match other industries like oil and gas.

The purpose of the Petro-HRA project, sponsored by the Norwegian Research Council and Statoil, is to bridge existing nuclear-based HRA to the domain of oil and gas. Like nuclear power, oil and gas are a safety critical enterprise in which the consequences of human actions or inactions can be severe in terms of impact to the environment, economy, or individuals. As with nuclear power, although there is a potentially high consequence should something go wrong, the incidence of negative events is quite rare. There are manifold safety barriers put in place to ensure that faults do not occur or that, if they do occur, their effects are quickly minimized. This defence in depth concept of operations permeates both nuclear power and petroleum operations.

The Petro-HRA project consists of several parallel activities to identify best practices in HRA and adapt them to a petroleum context. An initial review (Gould, Ringstad, and van de Werwe, 2012) identified the Standard Plant Analysis Risk Human Reliability Analysis (SPAR-H) method (Gertman et al., 2005) as a promising method for use in a petroleum context, because it represents a simplified approach to HRA using a worksheet to identify sources of human error and quantify them. Its simplicity may be deceiving, however, as additional guidance has been necessary to ensure the method is applied in a systematic and consistent manner (Boring et al., 2006; Whaley et al., 2012). Still, the straightforward assumptions and application of the method make it uniquely flexible for use and adaptation to other domains beyond the nuclear domain for which it was originally developed. For example, the method has been adopted for aerospace applications by NASA (Chandler et al., 2006).

---

[*] Corresponding Author: Ronald.Boring@inl.gov

Figure 1(a): Conceptual interaction of the human and system as part of overall risk.

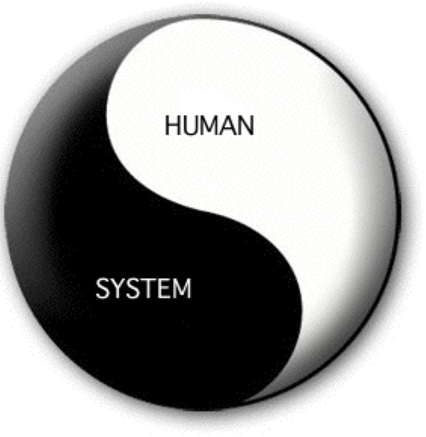
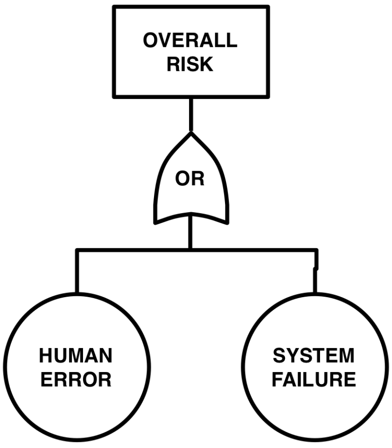


Figure 1(b): Fault tree representation of human error and system failure as part of overall risk.



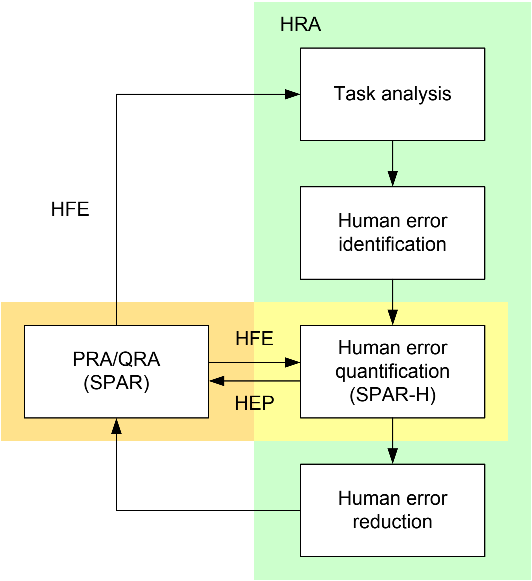
HRA, as part of the probabilistic safety assessment (PSA) in nuclear power and as part of the quantitative risk analysis (QRA) in the oil and gas sector, serves as a way to identify the human contribution to potential system risk. HRA is predicated on the idea of human error—any human action or inaction that has undesired consequences. As depicted conceptually in Figure 1(a) or as a simplified fault tree in Figure 1(b), overall risk is a composite of system or hardware failures and human errors (independently modelled as an OR-gate, or through a more complex combination). It is important to note that not all human errors or hardware failures have a negative consequence, and both QRA and HRA focus primarily on those failures or errors that are risk significant.

When a human error is determined to be risk significant (a process accomplished via a screening analysis), it is incorporated into the QRA. The human error is called a human failure event (HFE), a basic event that represents the failure of a component, system, or function in which humans are involved. In this context, the main purpose of HRA is to provide quantitative input to the QRA in the form of the HEPs of the HFEs. This human error quantification (HEQ) is a central part of an HRA as illustrated in Figure 2.

HEQ is accomplished using specific HRA methods. In Petro-HRA the HEQ—providing HEPs of HFEs as input to the QRA—will be performed by a petroleum industry adapted SPAR-H method. SPAR-H (Gertman et al., 2005) was developed as an easy-to-use HRA method for the Standardized Plant Analysis Risk (SPAR) models, which are plant-specific PRAs maintained by the U.S. Nuclear Regulatory Commission (U.S. NRC). The idea behind the SPAR models is that the regulator will have an independent PRA for each plant that may be compared to the utilities' PRA for that plant. This process facilitates independent evaluation of plant safety by the regulator. SPAR-H provides a standardized and simplified approach to HRAs within each plant's PRA at the U.S. NRC. Utilities perform HRAs in parallel to the regulator using SPAR-H or other methods.

It is important to note that SPAR-H, as a simplified method, only covers a single phase in Figure 2—human error quantification. SPAR-H (Gertman et al., 2005; Boring et al., 2006; Whaley et al., 2012) does not specify how the human errors should be modeled. This is an artifact of its primary use in nuclear risk analyses, in which the human errors to be identified are predefined based on opportunities for hardware failure influenced by human activities (see Boring and Joe, 2014, for a discussion). This predefinition does not as readily occur in the petroleum context, and it is therefore essential that the Petro-HRA project clearly articulates how to model human errors.

Figure 2: Human error quantification as a central part of HRA.



The SPAR-H method has numerous advantages as an HRA quantification approach, including:

- *Ease of use:* The method was specifically developed to focus only on quantification. It uses a simple worksheet and checklist approach that can be readily completed by non-expert analysts.
- *Proven track record:* The method has been widely deployed, as witnessed by its use for HRAs for every nuclear power plant in the U.S. It has also been adopted by NASA for use in space HRA (Chandler et al., 2006) and by Statoil for use in oil and gas (Gould et al., 2012; van de Merwe et al., 2012).
- *Flexibility:* The method is based on performance shaping factors (PSFs), which are those aspects of the task, individual, organization, and environment that influence human performance. SPAR-H uses eight PSFs. These PSFs are treated as multipliers on a nominal HEP, whereby the PSF may either increase or decrease the HEP depending on the level assigned to that PSF by the analyst (Boring, 2009). While the eight PSFs used in SPAR-H are optimized for nuclear power applications, they are generic enough that they represent a good approximation of human performance across industries. Additionally, it may be possible to fine-tune either the PSF list or its accompanying multipliers to better represent petroleum applications.

As noted, SPAR-H has already been used in support of HRA for the Norwegian petroleum industry (Gould et al., 2012). As such, it is a good candidate to explore and extend in the context of the Petro-HRA project. While SPAR-H has been selected as the method for use in Petro-HRA, lessons learned in its further application to petroleum can be generalized to other HRA methods as needed.

The primary objective of the Petro-HRA project is to test, evaluate and adjust SPAR-H (and if needed other HRA methods) as applicable for use in quantifying the likelihood of human error and identifying the impact of human actions on the post-initiator barriers in the main accident scenarios in the petroleum industry. This will create a better decision basis for managing risk in design and operations. One major thrust of the project focuses simplifying the task analysis and human error identification (HEI) analysis used in HRA by looking at how much of the task analysis can be reused for a new application. Simply put, current HRA is performed fresh for each scenario or offshore installation. Instead of requiring a new analysis for each scenario or installation, it is possible to see how similar or different the analyses are for the same type of tasks at different installations. A series of pre-analyzed HRA templates will be developed that can be adapted or reused for related analyses.

Another goal is to explore the differences in performing task analysis and human error identification for different analysts and to explore the possibility for guidelines that reduce the differences between analysts. This research could lead to considerable reduction in the cost of doing an HRA in the petroleum industry. Ultimately, this task will produce a library or database of reusable scenarios for petroleum HRA applications and guidance on how to adapt the scenarios without the need to perform completely new task analyses for many novel scenarios.

Another product of this research would be to investigate the extent to which clear guidance can be developed for bridging task analysis with traditional QRAs. In nuclear industry PRAs, HFEs are predefined in terms of disruptions to system function in which humans are involved, either by causing the failure or not preventing or mitigating the failure, and represent the basic unit of analysis in the HRA. When HFEs are not as clearly predefined, as is the case in the petroleum industry to date, a common set of tasks that act as HFEs is required. Without predefined HFEs or even an underlying approach to translate task analysis to HFEs, there is a threat for considerable inter-analyst variability in using the preferred SPAR-H HRA method. To some extent, a standard list of HFEs can be extracted from QRAs, specifically from the Defined Situation of Hazards and Accidents (DSHAs, pronounced *dee-shaws*) included therein. By creating a set of HFEs based on the DSHAs, HRA in general and SPAR-H in particular can more readily be applied to petroleum analyses.

To aid this goal, the remainder of this paper provides an identification and description of relevant DSHAs, establishing the foundation for further study and development of a library of HFEs.

2. THE DSHA, TARGET SYSTEM, AND HFE

DSHAs are defined in NORSOK Standard Z-013 (2010) as the "selection of hazardous and accidental events that will be used for the dimensioning of the emergency preparedness for the activity." These are representative accidents that are analyzed in the QRA in the Norwegian petroleum industry. DSHAs are also used to identify risks that can be protected against using defense in depth. Within the DSHAs are numerous human activities, including HFEs. The goal of this section is to review the DSHAs as they apply to target systems and HFEs for inclusion in HRAs.

Our DSHA analysis focuses on major accidents, specifically post initiators. The focus on major accidents is reasonable since these are the types of high consequence events that are modeled to a level where they may include HFEs. These are also the types of accidents that contribute significantly to the total risk (in addition to occupational accidents—"non-major accidents"—which are only calculated statistically without any modeling in the QRA).

The Petro-HRA project will only cover HFEs that are already modeled in the QRAs. It is not within the scope of the project to add new HFEs to the QRAs. In order to have a manageable set of HFEs for further analyses (generic task analyses and HEIs), we will focus on the most important HFEs, e.g., those included in the risk significant DSHAs. Thus, we will focus on those DSHAs—within the major accident DSHAs—that contribute most to the total risk, and the corresponding post-initiator barriers and HFEs.

Both of the last two points will be achieved by careful review of available QRAs.

QRAs are typically made and updated in several project phases, including the design phase (design risk analysis—DRA), construction phase (construction risk analysis—CRA), and the operation phase (usually just termed QRA). The main differences between a DRA, a CRA, and an as-built QRA are the level of information available at the time of analysis. Simple assumptions made in early phases may be explicitly modeled when sufficient information is available. The modeling of HFEs is most relevant when sufficient information is available. This will be the case in late stages of the design phase (to the extent modeling of HFE during design is feasible) and in the operation phase, which are the phases that will be focused on in the Petro-HRA project.

The petroleum industry covers both offshore and onshore facilities, and for the offshore facilities we can distinguish between certain types of installations. The Petroleum Safety Authority Norway (PSAN) distinguishes between the following five main categories of installations (Ptil, 2013a):

• Fixed production installations (fixed on the seabed)	20 installations
• Floating production installations (including semi-subs)	21 installations
• Production complexes (two or more bridged installations)	10 installations
• Normally unmanned installations (wellhead installations)	15 installations
• Mobile installations (jackups, floatels, drilling rigs/ships)	32 installations

The 98 installations that operated on the Norwegian Continental Shelf in 2012 were distributed approximately as indicated above (Ptil, 2013b).

The main purpose of defining the scope of the project is to ensure that we identify and select a reasonably representative set of HFEs through the relevant DSHAs and appurtenant post-initiator barriers. This means that we do not necessarily need to treat all the five main categories of installations separately if similar accident scenarios or DSHAs occur on several of the installation categories. Normally unmanned installations are relatively simple installations that we assume have no additional DSHAs compared to the other categories. Also, as they are normally unmanned there will normally not be HFEs included in post-initiator barrier models. Production complexes consist of two or more single installations that each can be considered as one of the other categories. It is therefore assumed that DSHAs and HFEs are covered by the other categories.

We are then left with the following installations/facilities with respect to the scope of the project:

- On-shore facilities
- Fixed production installations
- Floating production installations
- Mobile installations

Post-initiator barriers are the systems designed, implemented and operated—either manually or automatically—to prevent or mitigate an initiating event in developing into a full-scale accident. These post-initiator barriers are commonly called *target systems.*

An accident scenario is a specific path describing the development from an initiating event to an accident (top event) followed by consequences for humans, the environment, assets, or production (economy). It can also include the causes of an initiating event. A way of categorizing accident scenarios is to use DSHAs. The term was introduced in the Petroleum regulations related to emergency preparedness and is used by all operating companies. The DSHAs cover all the situations for which emergency preparedness is needed. They consist of three parts: dimensioning accidental events (DAEs), minor accidental events, and temporary increase in risk. The first part—the DAEs—are taken from the QRA and treated further in the Emergency Preparedness Analysis (EPA) together with the two other parts. This also means that the most important DSHAs from a QRA point of view are the DAEs. On the other hand, the EPA may also provide additional relevant information for the DSHAs that are selected for further identification of post-initiator barriers and HFEs.

There is no standardized list of DSHAs. The list differs from company to company and installation to installation, both with respect to what is included as a DSHA and also the numbering or sorting of the DSHAs. The only common list of DSHAs, that all operating companies are familiar with, is the list reported in Ptil (2013a). The list is found in Table 1. The first part of the list is the most relevant part, since we will focus on major accidents. Further, DSHA 10 and 11 are, in principle, related to major accidents but are not treated as part of the major accident indicator in RNNP anymore. Also, DSHA 12 is treated separately in RNNP and not included as part of the major accident indicators. Thus, a

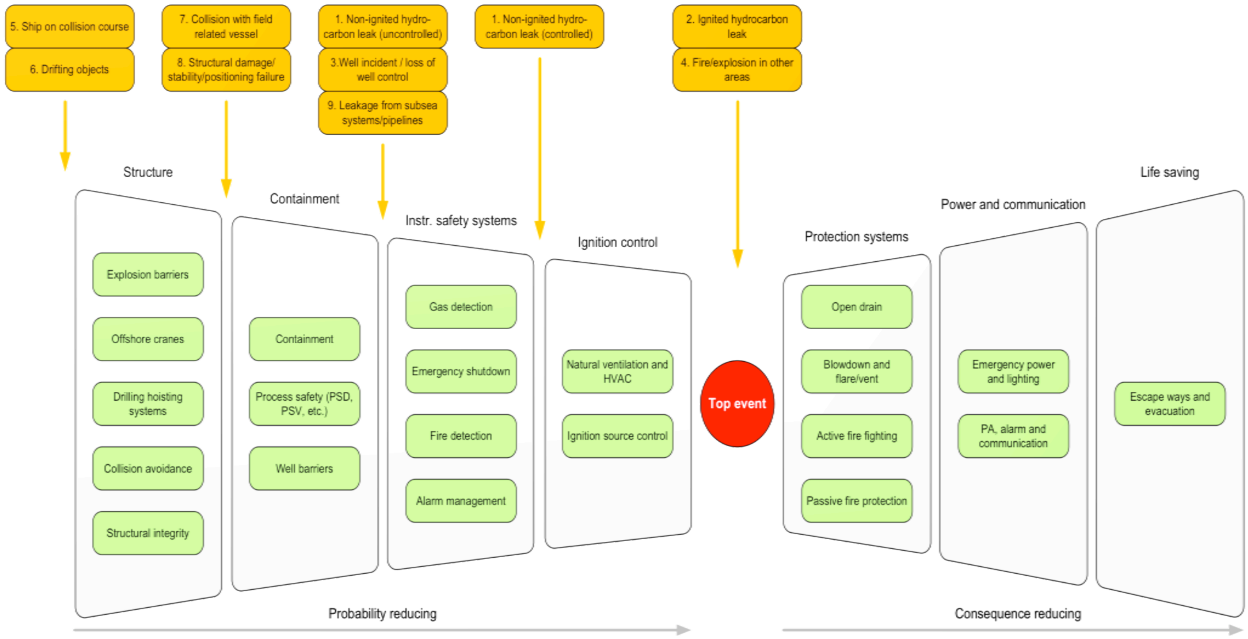
Table 1: DSHAs used in the Norwegian petroleum industry.

Major Accident DSHAs	**Non Major Accident DSHAs**
1. Non-ignited hydrocarbon leak	13. Man over board
2. Ignited hydrocarbon leak	14. Serious injury
3. Well incident / loss of well control	15. Serious illness/epidemic
4. Fire/explosion in other areas (non-hydrocarbon)	16. Blackout
5. Ship on collision course	17. Non-operational control room (*not in use*)
6. Drifting objects	18. Diving accident
7. Collision with field related vessel	19. Release of H2S
8. Structural damage/stability/mooring/positioning failure	20. Loss of control of radioactive source (*not in use*)
9. Leakage from subsea systems/pipelines/risers/ flowlines/loading buoy/loading hose	21. Falling objects
10. Damage on subsea systems/pipelines/diving gear caused by fishery equipment	
11. Evacuation (precautionary/emergency evacuation)	
12. Helicopter accident	

reasonable delimitation for the Petro-HRA project is to focus on DSHAs 1-9, which still will provide a good coverage of major accident scenarios.

It has been emphasized during the start-up phase of the Petro-HRA project that we should not limit ourselves only to gas leaks, but rather cover a broad range of scenarios and DSHAs. This is achieved by using DSHAs 1-9 as a starting-point for further identification of post-initiator barriers and HFEs. An illustration of the entry points of the DSHAs 1-9 is provided in Figure 3. The yellow boxes represent the DSHAs, while the green boxes represent the available barriers to mitigate accidents. In principle, all barriers to the right of the entry point for a given DSHA are potential post-initiator barriers or target systems for that DSHA. (The shape of the bow-tie should of course be specific for each DSHA, placing the top event directly under the entry point.) Not all barriers are relevant for all DSHAs, and there may also be other barriers than those shown in Figure 3.

Figure 3: Major accident DSHAs.



Defining the applicable HFEs for the DSHAs and target systems is the challenge, since neither the DSHA nor target system is a compatible unit of analysis for SPAR-H. The American Society of Mechanical Engineers (ASME) defines an HFE as “a basic event that represents a failure or unavailability of a component, system, or function that is caused by human inaction, or an inappropriate action” (2009). In this context, the HFE required by SPAR-H may be seen simply as a DSHA for which human error is clearly a contributor. That said, the context for the human error must then be defined, and the context must be translated into PSFs for use in SPAR-H. Here, the SPAR-H PSFs serve a dual purpose:

- *Identification of Vulnerabilities:* The PSFs can determine where human actions may be more likely to occur. For example, the PSF for *Available Time* could help the analyst determine if the time window to complete the required action is insufficient. While the PSFs in SPAR-H are quite general, they do provide a high-level set of vulnerabilities that may be aligned to DSHAs to account for contexts that increase the likelihood of human error.
- *Crediting Barriers:* The SPAR-H PSFs do, to a limited extent, credit successful human activity, including those factors that will decrease the overall likelihood of human error. The target systems should be considered to the extent they can positively weight a PSF in terms of human action. For example, a target system consisting of a collision avoidance system may alert a ship captain of a possible collision. This could be accounted for in the PSF for *Ergonomics and Human-Machine Interface*, which can significantly decrease the likelihood of human error.

It should be noted that the use of SPAR-H in this manner does not accord with the existing method guidance in Gertman et al. (2005), and it will be necessary to develop supplemental guidance to help analysts align the PSFs to vulnerabilities and barriers.

3. SUMMARY AND CONCLUSIONS

The Petro-HRA project will ultimately use and refine the SPAR-H method for use in human error quantification. An important stepping stone to that goal is to perform qualitative analyses—including task analyses and human error identification—on relevant HFEs. This paper has provided a brief review of relevant petroleum accident scenarios, as captured in the DSHAs, and target systems, as represented by the post-initiator barriers. These can and will be mapped to SPAR-H analyses in terms of PSFs.

Our preliminary review for risk significant, high consequence accidents suggests the following list of DSHAs:

- DSHA 1-2: Process accidents
- DSHA 3: Blowouts
- DSHA 5-7: Ship collisions
- DSHA 9: Riser and pipeline accidents

These serve as the basis for developing the candidate HFEs that will constitute the analysis re-use library that is a major product of the Petro-HRA project. For next steps, task and HEI analyses for the identified HFEs will be performed based on the literature, project reports, and workshops with end-users. Then the common and unique tasks and errors for each system will be identified. Next, HFEs will be identified and developed for each DSHA. Then a library consisting of tasks and human errors relevant for the identified HFEs will be compiled. The developed library will then be validated against traditional task and HEI analysis techniques using the established HFE as basis for comparison. As such, a comparison will be made between the traditional approach in QRA and the newly developed reusable library-based approach, providing insight into the advantages and disadvantages of such an approach. Finally, guidelines for applying the library will be developed.

Disclaimer

INL is a multi-program laboratory operated by Battelle Energy Alliance LLC, for the United States Department of Energy under Contract DE-AC07-05ID14517. This work has been carried out as part of The Research Council of Norway project number 220824/E30 "Analysis of human actions as barriers in major accidents in the petroleum industry, applicability of human reliability analysis methods (Petro-HRA)". Financial and other support from The Research Council of Norway, Statoil ASA and DNV are gratefully acknowledged. This paper represents the opinion of the authors, and does not necessarily reflect any position or policy of the above mentioned organizations. Neither the United States Government, nor any agency thereof, nor any of their employees makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately-owned rights.

References

American Society of Mechanical Engineers. (2009). *Addenda to ASME/ANS RA-S–2008, Standard for Level 1/Large Early Release Frequency Probabilistic Risk Assessment for Nuclear Power Plant Applications, ASME/ANS RA-Sa-2009.* New York: American Society of Mechanical Engineers.

Boring, R.L. (2010). How many performance shaping factors are necessary for human reliability analysis? *Proceedings of the 10th International Probabilistic Safety Assessment and Management Conference.*

Boring, R.L. (2009). Human reliability analysis in cognitive engineering. *Frontiers of Engineering: Reports on Leading-Edge Engineering from the 2008 Symposium* (pp. 103-110). Washington, DC: National Academy of Engineering.

Boring, R.L., & Blackman, H.S. (2007). The origins of the SPAR-H method's performance shaping factor multipliers. *Official Proceedings of the Joint 8th IEEE Conference on Human Factors and Power Plants and the 13th Annual Workshop on Human Performance/Root Cause/Trending/Operating Experience/Self Assessment*, 177-184.

Boring, R.L., and Joe, J.C. (2014). Task decomposition in human reliability analysis. *Proceedings of the Probabilistic Safety Assessment and Management (PSAM 12) Conference.* In press.

Chandler, F.T., Chang, Y.H.J., Mosleh, A., Marble, J.L., Boring, R.L., & Gertman, D.I. (2006). *Human Reliability Analysis Methods: Selection Guidance for NASA*. Washington, DC: NASA Office of Safety and Mission Assurance Technical Report.

Gertman, D., Blackman, H., Marble, J., Byers, J., Smith, C., and O'Reilly, P. (2005). *The SPAR-H Human Reliability Analysis Method, NUREG/CR-6883.* Washington, DC: US Nuclear Regulatory Commission.

Gould, K.S., Ringstad, A.J., & van de Merwe, K. (2012). Human reliability analysis in major accident risk analyses in the Norwegian petroleum industry. *Proceedings of the Human Factors and Ergonomics Society,* 56, 2016-2020.

Norwegian Oil Industry Association. (2010). *Risk and Emergency Preparedness Assessment, NORSOK Standard Z-013, Rev. 3.* Lysaker, Norway: Standards Norway.

Ptil. (2013a). *Risikonivå i petroleumsvirksomheten, Hovedrapport; Utviklingstrekk 2012, norsk sokkel. Rev. 2, 25.4.2013* (Risk level in the Petroleum activity, Main Report, Development trends 2012, Norwegian Continental Shelf, in Norwegian). Stavanger: Petroleum Safety Authority Norway.

Ptil. (2013b). *Risikonivå i petroleumsvirksomheten, Hovedrapport; Utviklingstrekk 2012, landanlegg. Rev. 2, 25.4.2013* (Risk level in the Petroleum activity, Main Report, Development trends 2012, Onshore Facilities, in Norwegian). Stavanger: Petroleum Safety Authority Norway.

Swain, A.D., & Guttmann, H.E. (1983) *Handbook of Human Reliability Analysis with Emphasis on Nuclear Power Plant Applications*, NUREG/CR-1278. Washington, DC: US Nuclear Regulatory Commission.

van de Merwe, K., Øie, S., and Gould, K. (2012). The application of the SPAR-H method in managed-pressure drilling operations. *Proceedings of the Human Factors and Ergonomics Society 56th Annual Meeting*, 2021-2025.