PETRO-HRA, A NEW METHOD FOR HUMAN RELIABILITY ANALYSIS IN THE PETROLEUM INDUSTRY

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The human contribution to the safety of petroleum installations has long been a concern for the industry. The quantitative risk analysis (QRA) used in the industry has traditionally focused on technical barriers, while the human aspect of risk has not been integrated in the QRA, or analyzed systematically. Human reliability analysis (HRA) methods have been applied in the nuclear industry for a long time, and the aim of this project was to test, evaluate, adjust and standardize HRA to accident scenarios in the petroleum industry. Many HRA methods focus on the quantification of the human error probability. Since a large part of the work to be done by analysts is the qualitative parts leading into the quantification, Petro-HRA also offer guidance for how HRA practitioners should perform the qualitative part of the analysis. This is especially useful in order to support new analysts with practical advice. Another major aim with the new method was to increase the efficiency of HRA analysis, and encourage re-use by establishing libraries of analyses and models. For the quantification part of the method, Petro-HRA took SPAR-H as a starting point, adjusting and adapting the performance shaping factors to the petroleum context. This paper presents an overview of the method.

I. INTRODUCTION

Petro-HRA is a method for qualitative and quantitative assessment of human reliability in the oil and gas industry. The method allows systematic identification, modelling and assessment of tasks that affect major accident risk. The method is mainly intended for use within a quantitative risk analysis (QRA) framework, but may also be used as a stand-alone analysis. The method is documented in a guideline report.[1] The aim of the Petro-HRA project was to test, evaluate and adjust HRA to post-initiating events in the petroleum industry. This project chose Standardized Plant Analysis Risk-Human Reliability Analysis, or SPAR-H,[2] as the primary method to adjust to the petroleum industry. The choice was based on an evaluation of different methods by Gould, Ringstad and Van de Merwe in 2012,[3] which concluded that SPAR-H was the most promising method for analyzing human reliability in post-initiating events in petroleum applications.

The method includes context-specific guidance on qualitative data collection and analysis, quantitative analysis, as well as integration in QRA. The Petro-HRA method should be used to qualitatively and quantitatively assess the likelihood of human failure. Although a thorough qualitative analysis is essential, the quantitative analysis has considerable value. The main purpose of quantitative analysis is to identify which tasks are most sensitive to human error, and which performance shaping factors (PSFs) have the greatest influence on error probability. This allows better prioritization of risk and risk-reducing measures. The quantification is also essential for direct integration into the QRA. The relation between HRA and QRA is illustrated in Fig. 1.

Human error is treated through the analysis of a human failure event (HFE), a basic event that represents the failure of a component, system, or function in which human actions are involved. The HFE is often defined in the QRA, but can also be modified by the HRA. One of the main purposes of HRA is to provide quantitative input to the QRA in the form of the human error probability (HEP) of the HFEs. As shown in Fig. 1, Petro-HRA covers all the steps of the HRA, not only the quantification part. Many HRA methods, including SPAR-H, only cover the quantification part of HRA. The level of detail in the HRA depends on the size and complexity of the accident scenarios being analyzed. Practical constraints related to e.g., time or plant access may also vary.

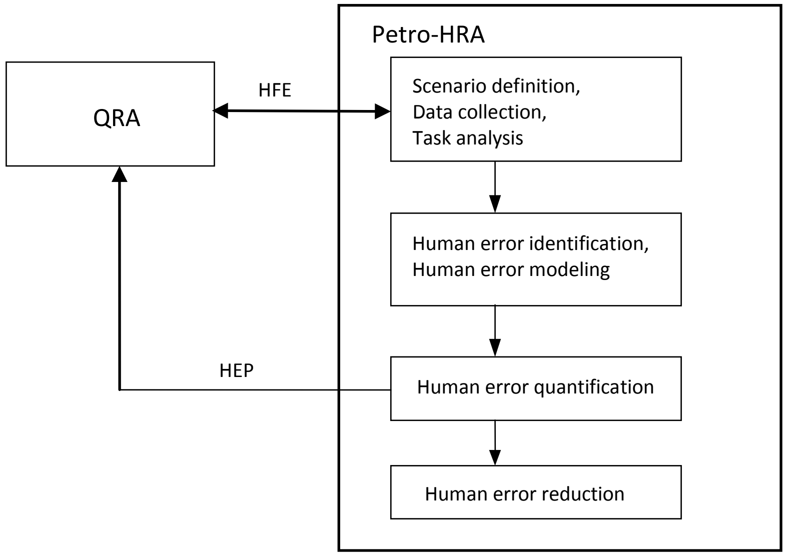

Fig. 1. QRA and Petro-HRA

A human error can be a cause or part of a cause in an accident scenario (pre-initiating events) or they can occur during a response after a major accident has started (post-initiating events). Petro-HRA is developed for and should be used to analyze human errors in post-initiating events, especially control room tasks as performed in e.g., process control, drilling or maritime (bridge) operations. The method is not specifically developed for analyzing pre-initiating events, such as causes for gas leaks or dropped crane loads. However, the method may also be used to analyze a broad set of tasks, as long as the Petro-HRA PSFs are the most important influencing factors.

II. THE PETRO-HRA METHOD

Petro-HRA consists of eight steps: 1) Scenario definition; 2) qualitative data collection; 3) task analysis; 4) human error identification; 5) human error modelling; 6) human error quantification; 7) human error reduction; 8) documentation. The steps are numbered and described in a sequence, but HRA is not a linear process and there is often iteration between the steps throughout the whole process.

II.A. Step 1, Scenario Definition

The main aim of this step is to define the scenario that is to be analyzed. Scenario definition is one of the most important steps in the HRA, as it defines the scope and boundaries of the analysis and shapes the subsequent qualitative and quantitative analyses. Scenario definition can be difficult, depending on how well the Human Failure Events (HFEs) have been defined in the QRA. It is important that the scenario description is concise and contains specific information, which reflects the logic of the QRA model. The scenario description acts as a communication platform, it documents the assumptions made, and helps to create and maintain a common understanding of the scenario between the different people involved in the HRA and QRA processes.

The analyst should attend or arrange a number of *initial meetings*, such as: General QRA kick-off meeting; General Hazard Identification (HAZID) meeting; HRA kick-off meeting; Scenario meeting. The Petro-HRA guideline[1] contains a number of questions that can help the analyst in the meetings. Some of the key questions that the analyst should try to answer in these meetings are: What are the relevant Defined Situations of Hazard and Accident (DSHA) for this scenario? What HFEs are currently modelled in the QRA? What constitutes success or failure for these HFEs? Once the analyst has established the key parameters of the scenario and HFEs from the initial meetings, a *document review* should be performed to gather additional information to define the analysis scenario. It would be beneficial for the analyst to review documentation before the kick-off meeting as well. The objective of the document review is to collect and understand information about: The role of the operator in the scenario, and the tasks that operators are required to perform; The function of plant systems in the scenario, and where human-system interaction is likely to occur; The location and layout of relevant plant systems and human-machine interfaces (HMIs); The systems, tools and other resources that the operators are likely to use in the scenario, and; The results of previous analyses performed that are relevant to the scenario. Documents that would typically be reviewed are: HAZID report, Safety/barrier strategies, QRA report, any earlier HRA and Human Factors analyses reports, function and task analyses, emergency preparedness analyses, Hazard and operability (HAZOP) study reports, technical audits / verification of performance standards, incident or accident investigation reports, operating manuals / procedures / instructions, maintenance logs or other sources of operational experience.

There are several ways to describe the scenario, but as a minimum it should include the following: Location of event; External environmental conditions; Operational mode of the plant at the time of the event; Safety system/barriers; Personnel roles and responsibilities; Initiating event of the scenario; Intermediate events; End of event sequence; Duration of scenario.

The analyst can now perform an *initial task identification* using the information from the scenario description. The analyst can use this to organize the information collected to date about the operator tasks and to check whether there are any knowledge gaps in their understanding of how tasks relevant to the scenario are performed, which can be addressed in the qualitative data collection step. A simple Hierarchical Task Analysis (HTA) format is useful for performing the initial task identification, and it provides a good visual aid for talking through the scenario and discussing the task steps with operators and other Subject Matter Experts (SMEs) during the data collection step.

II.B. Step 2, Qualitative Data Collection

This step of the HRA involves a specific and focused data collection to enable a detailed task description, which includes information about factors that may (positively or negatively) affect human performance and the outcome of the scenario. This formal qualitative data collection step is usually performed via a scenario walk- and talk-through, observation of operators working in situ, interviews and discussions with operators and other SMEs. These activities generally take place either during a site visit to the plant, or a workshop with operators, or both.

One of the first activities that the analyst should perform is to talk and/or walk through the scenario with the operator(s). The purpose of the *talk-/walk-through* is for the analyst to gain a more detailed understanding of: The task steps that would be performed by the operator(s), and the order of sequence of steps; The time it will take to perform the task steps; The working environment within which the task steps will be performed; The systems and interfaces that the operator(s) will use; The use of operating manuals, procedures, instructions or other supporting documentation; and Communication and teamwork throughout the scenario. The walk-through is typically performed in the place where the operator(s) would be located when responding to the scenario being analyzed. A talk-through can be performed anywhere, although it is normally held in a different “offline” location, such as a meeting room, perhaps due to restrictions on access to the scenario location and/or to avoid disturbing or distracting workers in the location. Of course, the ideal situation would be to perform the talk-/walk-through at the site to enable the analyst to physically see the workspace, plant items and controls and displays that the operator would use. However, a task walk-through can still be performed in a workshop setting if the analyst has access to relevant photographs, layout drawings, etc. that the operators can point to as they talk through the scenario.

Task and training observations can provide valuable qualitative data about how operators work, interact with each other and the plant systems around them and how they react in abnormal situations. There are two main types of observations the analyst could perform: a) Observation of normal working conditions in a normal working environment, watching the operators as they perform their usual duties either in the control room or in the field. The analyst can observe how the operators work together, use the tools, equipment, displays and controls that are available to them, make decisions and carry out normal tasks; b) Observation of training exercises, ideally observing the actual operator response to the exact scenario being analyzed, including any difficulties that are encountered and also whether the human intervention succeeds or not. If it is not possible to observe the actual analysis scenario, it can still be useful to observe the operators in other training scenarios because the analyst can still collect information about the general response to an event, how the operating crew works together, how they communicate, how they use procedures or other documentation, how they use controls and interfaces, how they solve problems and how they make decisions.

Interviews are one of the most commonly used techniques for collecting qualitative data, to collect either a wide range of information about a scenario, or to investigate in more detail specific aspects of the scenario and task steps. The analyst should strive to interview a range of different people to get a more balanced view, e.g., operators; shift supervisor or manager; training supervisor; site QRA analyst/end user. It is possible to combine the interview or discussion with the scenario talk-/walk-through; this is usually the case for HRA, because it is natural to ask questions and discuss aspects of the scenario and tasks during the talk-/walk-through. This is usually followed up with a more structured interview or discussion afterwards, where the analyst can focus in on specific areas of interest or concern.

In addition to collecting information about the scenario and task steps, the analyst should also try to collect qualitative data about potential human errors that could occur and about the PSFs that could affect human performance. This information will inform the subsequent Human Error Identification (Step 4) and PSF evaluation as part of the Human Error Quantification (Step 6) respectively. The Petro-HRA guideline[1] contains detailed questions, prompts and advice to assist the analyst in collecting information about the tasks, potential human errors and PSFs during interviews and discussions.

Time is often an important, if not critical, factor in petroleum incidents, with operators having to respond within minutes or even seconds of the initiating event to control and mitigate the effects of the scenario. Therefore, a timeline analysis is often required to understand the relationship between operator actions, the time required to perform the necessary actions and the time that is available to the operator to perform these actions. The site visit/workshop offers a good opportunity to develop an *initial timeline* of the events and operator tasks in the scenario, as this can be checked and confirmed with operators during the interviews/discussions to ensure that the timeline is credible and reflects their experience or thoughts on how the scenario might unfold. The analysis maps out how long each major task takes (usually measured in seconds or minutes), and identifies where there may be tasks carried out in parallel, or where there may be dependencies between tasks (e.g. one task cannot be started until a previous task has been completed).

II.C. Step 3, Task Analysis

A task analysis is a description of the steps that are carried out as part of an activity, and it provides a systematic means of organizing information collected around the tasks. The level of detail of a task analysis can vary considerably, although the general guidance is to tailor the level of the analysis to the requirements at hand. The aim of the task analysis is to understand the activities that are being analyzed and to translate these details into the level of detail suitable for the HRA and QRA. A task analysis to support HRA will tend to be heavily grounded in identifying sources of human error, and it also helps to define the human failure event. The task analysis is also the basis for understanding the impact of the PSFs on the human tasks and thereby the basis for the quantification.

The information collected by the HRA analyst should be organized into a Hierarchical Task Analysis (HTA) and a Tabular Task Analysis (TTA), see Kirwan.[4] The HTA decomposes tasks hierarchically according to goals at the top level and the tasks at the lower levels that are required to accomplish the goals. For HRA, the HTA needs to decompose to the level where the analyst can look concretely at opportunities for error.

The HTA should then be extended into a tabular form to allow for the inclusion of more information than can be contained within the diagrammatic HTA. Although the TTA is more complex to develop than the HTA, it is more useful as a working document to allow the analyst to arrange more information in a logical and structured manner. The analyst must decide what data is needed for inclusion in the TTA, informed by the scenario definition and qualitative data collection steps. As a simple example, if there is a particular concern regarding a control room operator's ability to diagnose the event from the Human-Machine Interface (HMI) in the control room, then the TTA should be focused towards collecting information relevant to the HMI. In this case, tasks carried out in the field (i.e. outside the control room) may not be considered so important to the analysis and do not need to be represented in any great detail in the TTA. Proposed categories for the initial TTA are listed in the guideline,[1] typically including task number, description, cue, feedback, HMI, procedure and any assumptions and comments. The TTA will be expanded in the Human Error Identification (HEI) step, linking each task to potential errors and PSFs. It should be updated throughout the analysis and serve as an overview.

II.D. Step 4, Human Error Identification

The objective of the human error identification (HEI) is to 1) identify potential errors related to the tasks in the scenario, 2) identify and describe likely consequences of each error, 3) identify recovery opportunities; and 4) identify and describe performance shaping factors (PSFs) that may have an impact on error probability. HEI should be carried out in conjunction with (or following) the task analysis. A complete task analysis is required for HEI to be possible.

The HEI in Petro-HRA is carried out using the following steps, considering each task and task step in turn in terms of opportunity for error:

1. Identify "obvious" errors. Go through each task step and document the easily identifiable errors. For example, for a task "Detect visual alarms", the obvious error is that the operator does not detect the visual alarm.
2. Identify errors by using the SHERPA (Systematic Human Error Reduction and Prediction Approach)[5] guidewords. Revisit the task steps/sub-steps and, using the SHERPA guidewords as prompts, consider other less obvious types of errors that could occur. These error modes should be used as prompts to think about what potential errors could exist for the task and within the scenario. However, it is not important to categorize the errors to one or several of the error modes. Time and effort should be spent on identifying credible errors, rather than debating categories.
3. Identify and describe likely error consequences. The consequence of an error has implications for its criticality, and must therefore be described.
4. Evaluate recovery opportunities. If possible, determine the recovery potential of the identified error.
5. Identify PSFs. For each task and error, identify the PSFs that may influence performance.

Note any assumptions or uncertainties, and flag these for confirmation with a subject matter expert, for example, an operator or QRA analyst. Use an expansion of the TTA to document the analysis. A joint table in a spreadsheet for the whole TTA ensures that all the information for one task or task step is kept in one line in the table. Revisit the error identification several times throughout the remainder of the analysis as new information (e.g. from confirmation of assumptions) is received to check whether the errors remain credible and the associated information remain correct.

II.E. Step 5, Human Error Modelling (HEM)

One aim of the human error modelling is to model the tasks or events in such a way that when chosen individual tasks or events are quantified, the model logic can be used to calculate the HEP for the HFE that enters the QRA. Another aim is to clarify the links between the errors identified in step 4 (HEI), the PSFs that contribute to those errors, and the task or event that is chosen for quantification in step 6. These relations are then used qualitatively when each individual task is evaluated and quantified as described in step 6. Choosing which task/event to quantify in step 6 is done here in the modelling phase.

There are two approaches that are relatively standard in modelling: Event Tree Analysis (ETA) and Fault Tree Analysis (FTA).[4] Petro-HRA recommends using event trees in post-initiating HRAs because they match the sequential nature of a scenario, from one common initiating event which, depending on how the operator responds, can have several outcomes/ end states. Fault trees are preferred for pre-initiating HRAs where it has to be demonstrated how different human errors, often occurring independently, can cause an undesired top event. However, analysts may use fault trees if she/he feels more comfortable with this methodology.

A clear definition of what constitutes operator failure ensures that only relevant events are included in the model. What constitutes success and failure in the scenario under analysis is crucial as, first, it determines which events are represented in the HRA model. A clear failure or success criteria determines how far into the event sequence the HRA team should pursue the analysis. Second, it determines the time-frame to consider in the HRA. The time it takes an operator to complete the tasks required to perform the barrier function determines the scope of the analysis. As such, understanding success and failure criteria for the scenario under analysis is important as it directly influences the events represented in the failure model and thereby the HEP. The timing aspect needs to be incorporated in each event definition. This will also influence the evaluation of the time for succeeding events. The following is advice on how to perform the modelling:

1. Build an event tree based on the task analysis, e.g., by building an operator action event tree.
2. Evaluate the errors that contribute to failure of the chosen task. This may be done by evaluating all the sub-tasks of the chosen task in the TTA. Identify the dominating error if any.
3. Find which PSFs that contribute to this error and thereby to the failure of the chosen task. These PSFs will be evaluated in detail for the chosen task in step 6.
4. After quantification of each chosen task in step 6, the event tree shall be used to quantify the HFE that enters the QRA.

II.F. Step 6, Human Error Quantification

The HFE is quantified based on a nominal value and a set of performing shaping factors (PSFs). The TTA and knowledge from the human error identification and the human error modelling phases should now contain the most needed information in order to be able to do the quantification. After the quantification, in addition to getting the Human Error Probability (HEP) as a number from 0 to 1 of the task/event under analysis, one should also gain a detailed understanding of the performance shaping factors (PSFs) that are relevant for the event under analysis.

II.F.1. Nominal value

The main components of the quantification of one task or event (HFE) in the Petro-HRA method are a nominal value and nine performance shaping factors. From a nominal value and the PSF multipliers a human error probability (HEP) is calculated. A nominal value is a value that is supposed to contain all small influences that can contribute to errors on a task that are not covered by the performance shaping factors. The nominal value in Petro-HRA for all tasks is 0.01, which means that a task fails 1 out of 100 times. This value is the same value as for diagnosis in SPAR-H[2,6] and this value was chosen because most tasks in an accident scenario involve a large cognitive component, especially so since Petro-HRA is made for control room tasks. The separation between diagnosis (cognition) and action tasks in SPAR-H is not included in the Petro-HRA method because there are no tasks that are only diagnosis or action tasks. All tasks are considered a combination of diagnosis and action. If a task should be an action task in SPAR-H the task has to include automatic information processing where a lower degree of cognitive activity is needed. Tasks become automatic if they are highly trained for. If this is the case, the moderate level positive effect on performance in the Training/Experience PSF should be used. If this level is used the HEP becomes 0.001 which is the same as for an action nominal task in SPAR-H.

II.F.2. Performance shaping factors (PSFs)

"*A PSF is an aspect of the human's individual characteristics, environment, organization, or task that specifically decrements or improves human performance, thus respectively increasing or decreasing the likelihood of human error*".[7] In Petro-HRA PSFs that have been shown in general psychological literature and in other HRA methods to have a substantial effect on human performance when performing control room tasks (or tasks similar to control room tasks) are included. There are nine PSFs in Petro-HRA: Time, Threat Stress, Task Complexity, Experience/Training, Procedures, Human-Machine Interface, Adequacy of Organization, Teamwork, and Physical working environment. Arguments for changes and adaptions in the PSFs from SPAR-H are described in several articles by Laumann, Rasmussen and Standal.[8, 9 and 10]

Each PSF has several levels and a corresponding multiplier. From the nominal values, the chosen levels, and corresponding multipliers, a human error probability is calculated. In the description of the PSFs and its multipliers, the method contains as clear definitions as possible, giving concrete advice to the analyst for choosing the correct PSF multiplier for the task under analysis. The purpose of this is to reduce the variability between analysts. However, it is important that the analysis is not a purely "mechanistic" exercise. It is the responsibility of the analyst to evaluate whether the PSF has an effect on the performance of the operator(s) for the given task. This must be documented and substantiated for each PSF. The purpose of this is to improve the transparency and reproducibility of the results.

When evaluating the appropriate multiplier level for a PSF, the analyst must evaluate all the levels and choose the one that fits best. One must especially consider the level above and the level below, and the border conditions between these multiplier levels, including considering the uncertainties in the evaluations. The choice must then be substantiated and documented. If one (or more) PSFs has the value HEP=1, then the HEP for the whole task shall be set to 1 regardless any other multipliers for other PSFs. In this case, this PSF is regarded such a strong performance driver so the task is certain to fail. If a failure probability (HEP) higher than 1 is found, the failure probability shall be set to 1. The lowest HEP that should be given on a single event or task is 0.00001 or 10-5 since there are small influences that could affect task performance, which makes it unrealistic that a HEP should be lower than this.

In Table 1 the levels for the PSFs are given. This paper only gives an overview of the method, and thus for a detailed instruction on how to choose the levels of each multiplier, consult the method guideline.[1]

TABLE I. Petro-HRA PSF Summary worksheet

Petro-HRA PSF summary worksheet			
Plant		**Date**	
Event			
PSFs	**PSF levels**	**Multiplier**	**Substantiation. Specific reasons for selection of PSF level**
Available time	Extremely high negative	HEP=1	
	Very high negative	50	
	Moderate negative	10	
	Nominal	1	
	Moderate positive	0.1	

	Not applicable	1	
Threat stress	High negative	25	
	Low negative	5	
	Very low negative	2	
	Nominal	1	
	Not applicable	1	
Task complexity	Very high negative	50	
	Moderate negative	10	
	Very low negative	2	
	Nominal	1	
	Moderate positive	0.1	
	Not applicable	1	
Experience/training	Extremely high negative	HEP=1	
	Very high negative	50	
	Moderate negative	15	
	Low negative	5	
	Nominal	1	
	Moderate positive	0.1	
	Not applicable	1	
Procedures	Very high negative	50	
	High negative	20	
	Low negative	5	
	Nominal	1	
	Low positive	0.5	
	Not applicable	1	
Human-machine interface	Extremely high negative	HEP=1	
	Very high negative	50	
	Moderate negative	10	
	Nominal	1	
	Low positive	0.5	
	Not applicable	1	
Adequacy of organization	Very high negative	50	
	Moderate negative	10	
	Nominal	1	
	Low positive	0.5	
	Not applicable	1	
Teamwork	Very high negative	50	
	Moderate negative	10	
	Very low negative	2	
	Nominal	1	
	Low positive	0.5	
	Not applicable	1	
Physical working environment	Extremely high negative	HEP=1	
	Moderate negative	10	
	Nominal	1	
	Not applicable	1	

When having calculated a HEP for an event, it is good practice to do a sanity check, or reasonableness check. This check could be seen as a separate step, but in Petro-HRA it is considered a sub-step of the quantification. In addition one should include a normal quality assurance of the documentation, see step 8.

II.G. Step 7, Error Reduction

One of the main drivers behind an HRA is the opportunity it provides for improving a system's safety and reliability by implementing risk-informed solutions. Such improvements aim at minimizing risk either through reduction of human error probability or mitigating their consequences in case they occur. This risk (error) reduction process is made up of two closely linked and iterative activities, namely impact assessment and error reduction analysis.

The purpose of an impact assessment is to demonstrate the relative contribution of human error to the QRAs (or other risk model's) overall risk picture. Conclusions from the impact assessment help the analyst to determine the scope and depth of the error reduction analysis. Such an analysis aims to develop error reduction measures targeting specific human errors, and/or error reduction strategies targeting human performance on a more general level, for example across several tasks and accident scenarios. The objective of human error reduction is to develop measures and strategies in a systematic manner by utilizing knowledge and insight gained from analysis techniques commonly performed as part of an HRA. A detailed method for error reduction is explained in the method guideline[1].

II.H. Step 8, Documentation of the Petro-HRA

In a Petro-HRA, a final report must be written detailing the results of the Petro-HRA, and is issued as an appendix to the QRA. The quantitative results of the Petro-HRA (i.e. the calculated HEPs) will normally be input directly to the QRA fault tree or event tree models. However, the qualitative results are also important and so must be documented in a way that makes them sufficiently transparent for others who wish to read, understand and use those results. The QRA analysts, and other interested parties, must be able to understand, clearly and unambiguously, the process and methodology that was followed throughout the Petro-HRA, and how the final results were attained.

III. CONCLUSIONS

The Petro-HRA method is a newly developed method that comprises the whole process of performing an HRA, including the qualitative and quantitative parts of the analysis as well as the integration in the overall risk analysis. The method has adapted the SPAR-H method to use in the petroleum industry.

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