Development of Early Warning Indicators Based on Incident Investigation

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Abstract: This paper explores the possibility of developing early warning indicators based on incident investigation. The use of early warning indicators may contribute to ensure that oil companies produce oil and gas without harmful spills. The incident investigated was a hydraulic oil leak from the Eirik Raude drilling rig during exploration drilling in the Barents Sea in April 2005. The incident is analyzed using influence diagrams, from which seven general barriers against hydraulic leaks have been identified. For each barrier both checkpoints and indicators have been developed, which provide information about the status of the barriers and early warning of potential spills. The work described in this paper has shown that it is possible to develop early warning indicators based on incident investigation. Several of the proposed checkpoints/indicators may have prevented the oil leak at Eirik Raude, if they had been in use prior to the incident.

Keywords: Early Warning Indicators, Incident Investigation, Offshore Industry, Oil Leak.

1. INTRODUCTION

Exploration of oil and gas in the Northern Regions, in areas such as the Barents Sea and Lofoten, is a controversial topic of social debate in Norway, particularly due to environmental and fisheries interests. Political acceptance for opening of these prospective exploration acreages depends on public confidence in the ability to produce oil and gas without any harmful spills. Some limited exploration activity is presently taking place in the Barents Sea and further expansion depends on the ability of the involved companies to avoid harmful spills during this initial activity. A zero tolerance regime for oil spills has been introduced for this area.

One way of improving the ability to produce oil and gas without any harmful spills is to use early warning indicators. The objective of the work presented in this paper is to explore the possibility of developing early warning indicators based on incident investigation. Investigations of accidents such as Longford [1] and Texas City [2] have pointed at the need for improved process safety indicators.

The incident investigated was a hydraulic oil leak from the Eirik Raude drilling rig in April 2005 [3-5]. Influence diagrams are used to describe the incident and to identify barriers. For each barrier both checkpoints and potential early warning indicators are developed, which provide information about the status of the barriers. Some of the checkpoints/indicators developed are; i) Check depressurization of isolated systems/rate of inadequate depressurization of isolated systems, ii) Check the use of work permits (WP) and safe job analyses (SJA) when de-isolating systems/rate of inadequate use of WP and SJA, iii) Check that visual inspection is carried out/rate of inadequate visual inspection of system prior to use, iv) Check the critical overdue maintenance log/number of critical corrective maintenance work orders in backlog.

The preliminary work described in this paper shows that it is possible to develop early warning indicators based on incident investigation; in particular operational type of indicators. This is of course strongly influenced by the quality and depth of the incident investigation.

One important finding is that we need to adapt the frequency of data collection for estimating indicator values to the situation at hand, e.g. the time-frame of the operation, and this may differ for each of the

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indicators. The set of indicators should not be forced into the same data collection interval just for the convenience of the data collection.
Several of the proposed checkpoints/indicators may have prevented the oil leak at Eirik Raude, if they had been in use prior to the incident. The use of this kind of early warning indicators is crucial for single barrier systems. A failure in a single barrier system will result in spill to the sea because there are no additional systems to collect the released fluid before it ends in the sea.

Even though the Eirik Raude incident got large public and media attention that surpassed the seriousness of the incident, the offshore industry cannot afford the reoccurrence of such incidents, if they want to expand their activity in areas regarded as environmental sensitive.

2. DESCRIPTION OF THE INCIDENT

The Eirik Raude incident description is based on the investigations performed by Ocean Rig [3], Statoil [4] and Petroleum Safety Authority Norway (PSA) [5].

The drilling rig Eirik Raude was drilling the wildcat well 7131/4-1 located in the Barents Sea for Statoil. On April 12, 2005, at 3:30 p.m., the Blowout Preventer (BOP) carrier on the Eirik Raude drilling rig was taken out of isolation (i.e., connected to the hydraulic ring line) to enable the BOP skid frame to be removed in order to allow the installation of the work platforms for slip joint work. The BOP carrier had been run just 24 hours prior to this new de-isolation, meaning that the existing isolation permit and SJA (Safe Job Analysis) were still active.

When the BOP carrier was put on line, a leak was detected and the system was isolated by the senior subsea engineer (job supervisor). Upon inspection of the BOP carrier system below deck, it was apparent that the leak came from the drag chain system. The operation was stopped immediately. Approximately 1000 litres of hydraulic fluid (mineral oil of type Shell Tellus Oil T32) were lost to the sea.

Due to the weather conditions (temperature and wind) and the nature of the flow through the burst hose, the spilled fluid was dispersed with no possibility for the Standby Vessel to contain the fluid.

The low water solubility and low acute toxicity indicate that the discharge of hydraulic oil from Eirik Raude did not cause any significant acute toxic effects to organisms in the water column. Dispersed oil may cause some smothering (physical) effects of aquatic organism and affect some organisms on the surface. However, due to the limited amount of oil, the effects were restricted to the individual level, and the spill did not cause any acute effects on population level of either aquatic or surface living organisms.

The drilling operation was suspended for 18 days due to the incident.

An illustration of the technical system and personnel involved before and after the burst of the hydraulic hose is shown in Figure 1[†]. (Blue nodes illustrates what functioned as planned, whereas red nodes illustrates what went wrong, i.e., deviated from the intended outcome.)

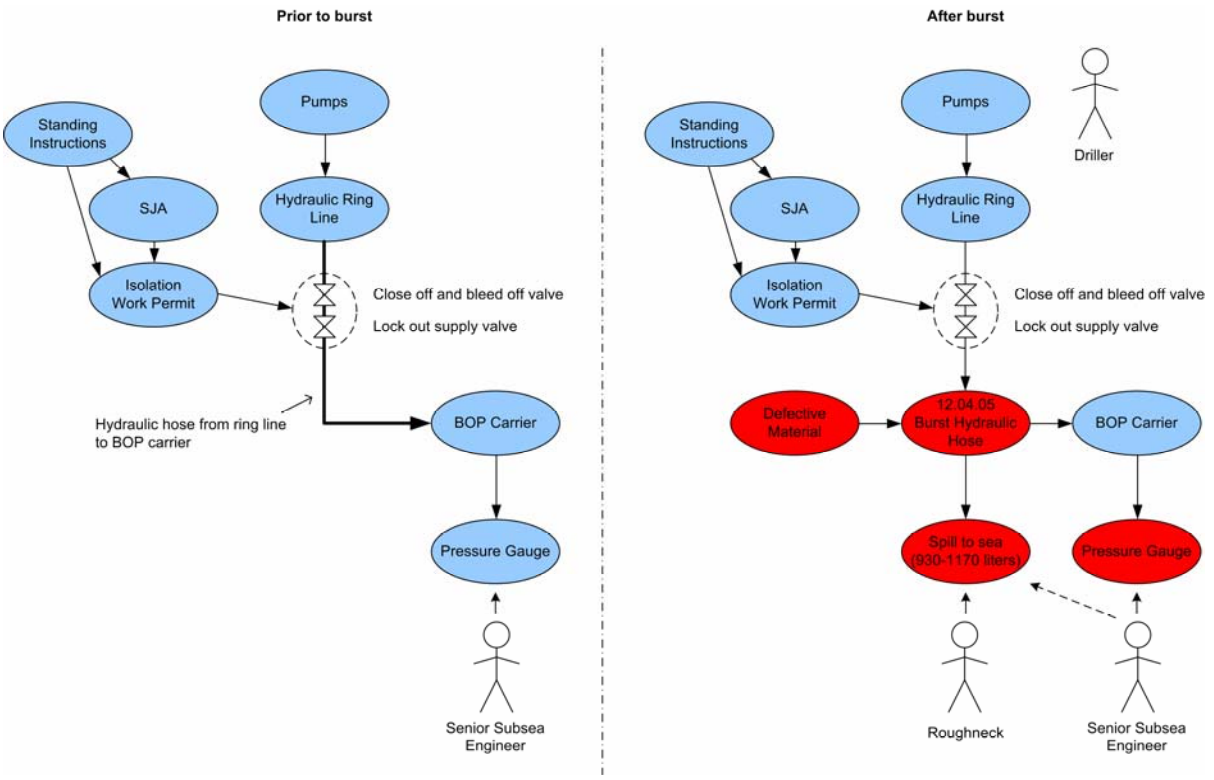
3. ANALYSIS OF THE INCIDENT

3.1. Direct Causes

The direct cause of the incident was mechanical wear and tear of the hydraulic hose over time resulting in burst of the hose as a consequence of defective material [4].

[†] Influence diagram-like illustrations are used throughout the paper. The diagrams show causal connections, but they do not follow stringent rules for Bayesian Belief Networks or influence diagrams [6].

Figure 1: Situation before and after the burst of the hydraulic hose



A contributing factor was that the hoses (placed in a drag chain) were located under deck, and thereby exposed to seawater/sea spray. This contributed to corrosion of the armour braiding and increased risk for leaking hydraulic fluid to sea, as compared to routing the ring line above deck.

The reason why the hoses were located under deck was to protect the hydraulic ring line system for the BOP carrier against mechanical damage. This was according to the prevailing design philosophy.

3.2. Contributing and Root Causes

Some of the contributing causes were [3]:

- Inappropriate design/construction
- Failure to warn/notify about difficult access for inspection
- Inadequate maintenance and maintenance routines
- Vague organisation of responsibilities – management of change
- Lack of knowledge/training

Lack of knowledge/training is directly linked to inadequate maintenance and will be treated in connection with inadequate maintenance and maintenance routines. Failure to warn/notify and vague organization of responsibilities will be left out due to lack of space.

3.2.1 Inappropriate design/construction

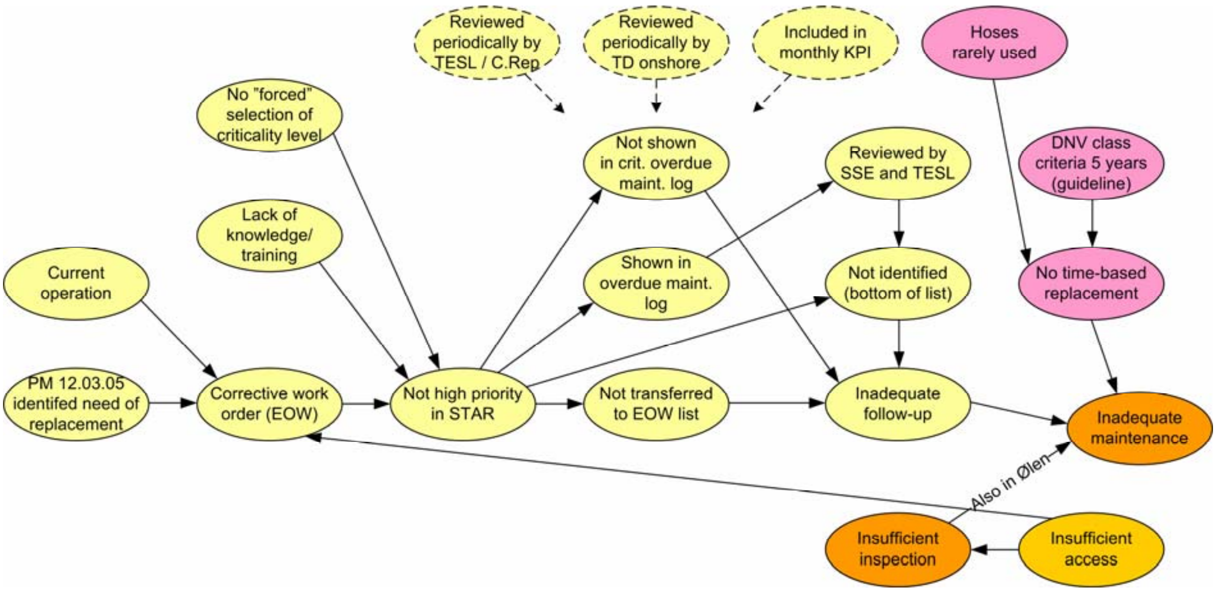
The main reason why the defect hoses were not changed prior to the burst was inadequate maintenance and inappropriate design. The hydraulic hose for the BOP carrier system was manufactured 10 cm too short according to specifications. Hence the hose was incorrectly installed by the shipyard, introducing too high specific pressure from the support bars onto the outer rubber lining of the hose. Due to the extensive mechanical wear and tear, the pressure containing braiding was exposed to the environment (e.g., salt water), resulting in corrosion and general weakening of the hose until it busted.

The risk concerning the design and arrangement of the hydraulic ring line system had been assessed and found acceptable according to normal industry practice following extensive review related to the zero discharge upgrade project. However, current arrangements lack two separate and independent physical barriers against accidental loss which is introduced as the "new standard" for operations in this environment.

3.2.2 Inadequate maintenance and maintenance routines

The underlying causes of inadequate maintenance are illustrated in Figure 2 (pink and yellow nodes[‡]).

Figure 2: Underlying causes of inadequate maintenance



A hose inspection was performed during shipyard stay in Ølen by the hydraulic engineer; however, the problem with difficult/insufficient access led to insufficient visual inspection, and thus inadequate maintenance. No hoses were identified to be replaced in the BOP carrier drag chain during the shipyard stay in Ølen. Based on a review of the preventive maintenance (PM) register, no replacement has been performed for these hoses since fabrication in Halifax, Canada in 2002.

A specific maintenance schedule for replacement of hydraulic hoses has not been defined in the PM system. A DNV Class criterion of replacement every 5 years exists as guideline for such replacements, but no written instruction of replacement every 5 years has been identified. An argument for not following this guideline is that these hoses are rarely used.

The PM work order for the BOP carrier completed March 12, 2005 by the senior subsea engineer (SSE) stated that one hose needed replacement. The signs of damage were spotted during visual inspection despite the fact that this was not discovered during the shipyard stay in Ølen (autumn 2004). A corrective work order was prepared in the PM system the same day by the senior subsea engineer to perform this job at the end of the drilling operation ("End of well" - EOW). The work was postponed due to lack of proper access to the hydraulic hoses during the current operation.

The maintenance system (named STAR) allowed for corrective work orders to be prepared and saved without forced (mandatory) selection of a criticality priority level. A criticality priority level was not selected for this specific corrective work order. If the job had been marked as "high priority", it could

[‡] Pink nodes cover time-based replacement. Yellow nodes cover inspection (part of PM) and repair/corrective maintenance (CM).

have been identified in the "Overdue Maintenance Log Report No.: 2.91C" listing overdue high, medium or low classified jobs. This critical overdue maintenance log is reviewed periodically by both the technical section leader (TESL), the company representative (C.Rep), and the Ocean Rig technical department (TD) onshore. Also, any overdue high critical maintenance jobs will be identified through the monthly Ocean Rig KPI review performed at the end of each month.

The corrective job was, however, included in the "Overdue Maintenance Log Report No.: 2.91" also used for work order review onboard, but still it was not identified by either senior subsea engineer or technical section leader.

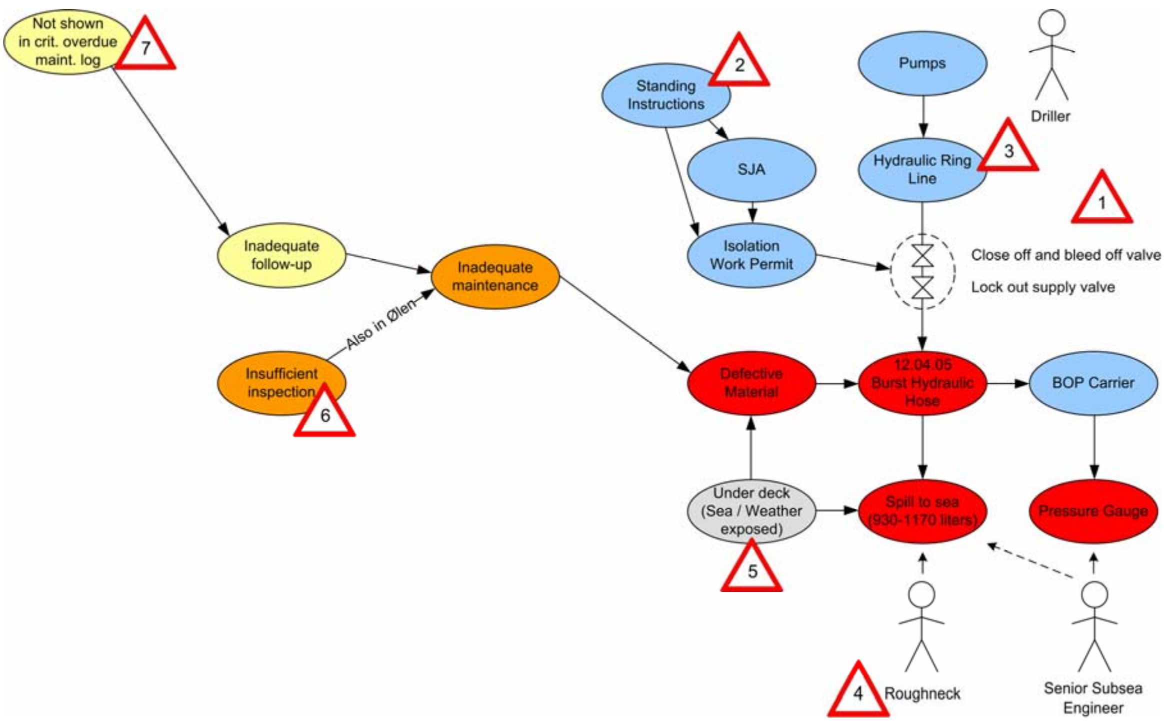
An EOW list is prepared by the section leaders to plan critical activities between drilling periods, but this particular corrective work order was not transferred to this EOW list for further action, since it did not include the criticality priority level.

All of this resulted in inadequate follow-up of the identified and reported damaged hose.

4. IDENTIFICATION OF BARRIERS AND EARLY WARNING INDICATORS

Important barriers to avoid hydraulic leaks are identified from the influence diagrams describing the incident. This is carried out by systematically reviewing each node starting from the consequence side and working towards the causal side. The barriers that have been identified are general in the sense that they are applicable to all of the (about 20) hydraulic systems onboard the rig, not only the hydraulic hoses for the BOP carrier. The location of the seven barriers identified for critical hydraulic systems are illustrated in Figure 3.

Figure 3: Identified barriers for critical hydraulic systems



The influence diagram in Figure 3 is an extract from the complete influence diagram of the incident. (The complete influence diagram has altogether 50 nodes.)[§]

[§] A red triangle is used to symbolize a barrier. Grey node refers to design/construction of the system (hydraulic ring line). Orange nodes cover two main aspects of maintenance that was deficient. Yellow nodes cover maintenance in more detail. (However, recall that Figure 3 is just an extract of the complete influence diagram.)

The identified barriers against hydraulic leaks are:

1. Close off/lock off valves for system isolation
2. Use of standing instructions for system de-isolation
3. Visual inspection of system prior to use
4. Monitoring of valve operation by personnel permanently located at isolation valve
5. Use of system under controlled weather conditions
6. Inspection of hoses according to PM program
7. Periodical review of critical overdue maintenance log

If the status of these barriers is unsatisfactory, then this information provides an early warning of a potential hydraulic leak incident. The status can be provided and expressed in various ways. As a preliminary result we have established a set of checkpoints, i.e. whether each barrier are in place (one hundred percent) or not. These checkpoints provide early warning information/indications, and may also be used to establish indicators, i.e. measure to what degree each barrier is intact. This will be discussed in the next section. The barriers and corresponding checkpoints are presented in Table 1.

Table 1: Barriers and information providing early warning indications of potential hydraulic leaks

Barrier		Checkpoint
1	Close off/lock off valves for system isolation	Check depressurization of isolated systems
2	Use of standing instructions for system de-isolation	Check use of WP/SJA when de-isolating system
3	Visual inspection of system prior to use	Check that visual inspection is carried out
4	Monitoring of valve operation	Spot check presence of watchman
5	Use of system under controlled weather condition	Check/verify that restrictions are followed
6	Inspection of hoses according to PM program	Check/follow-up PM-program
7	Review of critical overdue maintenance log	Check the critical overdue maintenance log

4. DISCUSSION AND CONCLUSION

The first five checkpoints in Table 1 may be seen as providing binary information, i.e. either the barriers are in place or not. Hydraulic systems not in use should always be depressurized; work permit and safe job analysis should always be used prior to system de-isolation; visual inspection of the system should be performed prior to use; a watchman should be placed at the isolation valve during operation of the system; and weather restrictions should be complied with.

Any deviations should be rectified immediately. This is similar to functional testing of safety systems (technical barriers); if a failure is detected, then the system should be repaired as soon as possible (and not only registered as a failure in a test report).

It is possible to use the information from the first five checkpoints as indicator values, i.e. the number of times each barrier are not in place divided by the number of checks/inspections. A negative trend in these values will provide early warnings of possible hydraulic leaks.

In situations with continuous operation, such as offshore production installations, it is typically assumed that indicator values are updated at regular intervals, such as every three months [7]. On drilling rigs the situation is quite different, and the interval for updating indicator values has to be adjusted to the operating period. The drilling of a well takes typically one to two months, and “early warnings” with respect to minor events such as hydraulic leaks must be viewed in this time-frame.

The first five checkpoints could be carried out as frequently as every day, first of all to make immediate rectification if any of the barriers are not in place. Secondly, the daily checks could be aggregated to weekly indicator values to provide trends from one week to another. Any negative development within the time-frame of the drilling operation may then be identified and rectified.

The last two checkpoints are somewhat different from the other checkpoints. They usually do not provide only binary information (i.e., okay or not), since it is rather common that there are backlogs both with respect to preventive maintenance (PM) and corrective maintenance (CM). So, we are interested in the amount of overdue maintenance work, and follow-up the trend from week to week. However, due to limited access to the systems that need to be maintained during drilling, many work orders are postponed until after the drilling period (i.e., EOW), which means that we may need to view the trend in amount of maintenance backlog in a longer time-frame.

Preliminary suggestions for early warning indicators are presented in Table 2. We have also proposed a data collection frequency for each of the indicators.

Table 2: Early warning indicators

Early warning indicators		**Data collection frequency**
1	Rate of inadequate depressurization of isolated systems	Daily
2	Rate of inadequate use of WP and SJA	Daily/Weekly
3	Rate of inadequate visual inspection of system prior to use	Daily/Weekly
4	Rate of inadequate use of a watchman	Daily
5	Rate of failure to comply with weather restrictions [a]	Daily/Weekly
6	Number of PM work orders for hydraulic hoses in backlog	Weekly/Monthly/Quarterly
7	Number of critical CM work orders in backlog [b]	Weekly/Monthly/Quarterly

[a] Given bad weather, i.e. not counting use of hydraulic systems in good weather
[b] Not necessarily restricted to hydraulic hoses

The set of early warning indicators, when finalized, can be further developed into a practical tool to be used by e.g. the oil company representative (or environmental advisor) onboard the rig, or by the rig company itself.

Several of the proposed checkpoints/indicators may have prevented the oil leak at Eirik Raude, if they had been in use prior to the incident. The use of this kind of early warning indicators is crucial for single barrier systems. A failure in a single barrier system will result in spill to the sea because there are no additional systems to collect the released fluid before it ends in the sea.

The use of indicators can be seen as a regulatory requirement [8] and/or a means to avoid unwanted events. Investigation reports of accidents such as Longford [1] and Texas City refinery [2] recommend the use of indicators. However, except for warning against the solely use of the lost time incident rate (which has nothing to do with process safety), they do not suggest or recommend specific indicators. The investigation report of the Texas City refinery accident [2] recommends the use of the recently published HSE[**] guide for developing process safety indicators [9]. HSE refers to, and recommends, the use of both leading and lagging indicators (the concept of 'dual assurance'). So far, we have mainly focused on leading indicators, since they provide early warning. We could also have included lagging indicators, such as the number of actual spills. However, even if it provides a warning, it is hardly "early"; it is rather "too late".

One challenge with the establishment of early warning indicators for potential minor events such as hydraulic leaks is that these events are not included in the current quantitative risk analysis (QRA) used in the offshore petroleum industry. Thus, we cannot deduce the importance of a change in indicator values, as we may for risk indicators [7]. Neither can we use precursor analysis (to quantify the seriousness of the event), since the event is not linked to a quantitative risk analysis.

[**] HSE – Health and Safety Executive (UK)

This study has been limited to minor unwanted hydraulic leaks, whereas harmful spills may also come as a result of major accidents (e.g., blowout) and discharge of "regular" spills (e.g., overflow of scuppers and drains). Barriers against these kinds of spills need to be controlled as well.

We have also focused mainly on operational indicators with a clear link to the particular type of event we want to avoid. We have paid less attention to organizational type of indicators far back in the causal chain, since the link to potential hydraulic leaks may be rather vague and also because all relevant organizational issues are not sufficiently treated in the investigation of a relatively minor event such as the Eirik Raude incident.

The preliminary work described in this paper has shown that it is possible to develop early warning indicators based on incident investigation; in particular operational type of indicators. This is of course strongly influenced by the quality and depth of the incident investigation. One important finding is that we need to adapt the frequency of data collection for estimating indicator values to the situation at hand, e.g. the time-frame of the operation, and this may differ for each of the indicators. The set of indicators should not be forced into the same data collection interval just for the convenience of the data collection.

5. FURTHER WORK

The specific indicators presented still need to be made operational and to be validated; at least obtain necessary face validity, i.e. a convincing agreement between the theoretical definition (the barrier) and the operational definition (the indicator).

We also need to develop early warning indicators or other control measures in order to avoid harmful spills from major accidents and discharge of "regular" spills.

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