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A STUDY ON RIG-PLANT HAZARDS AND EFFECTIVE MEASURES OF TREATING FLUID CONTAMINATIONS FROM CHEMICAL PROCESS UNITS.

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ABSTRACT

The complex and cost effective nature of process rig plants remain a matter of concern toward improving the operations and minimizing costs to bearest standard. Maintaining the unit operational equipments and replacing nonfunctional ones is another subject of concern in this research work. Minimizing rig plant hazards to near zero is the crux of the subject matter. There are several measures from the literatures; however, the adopted methods used here are (i) questionnaire for sifting hazards, (ii) assessing the various types of drilling fluids, (iii) characterization of drilling fluids and (iv) evaluating the risk potential and alertness in drilling rig plants. The hazard and operability, HAZOP risk assessment tools show that all the barriers or controllers may fail to guide the formation fluid invasion into the wellbore (kick) leading to blowout. The consequence of a failed control blowout is fire, explosion, fatal loss of lives, and environmental pollution. The significance of this research work is to improve on the safety of rigged plant on the basis of a risk assessment and preparedness response in the case of emergency.

Keywords: Fluid contaminants, hazard analysis, oil, gas and rig plant

INTRODUCTION

Risk assessment (RA) also known as 'hazard analyses' or 'vulnerability assessment' is the procedure for identifying hazards and determining their possible effects on a community and environment. Risk or hazard by itself is not an event, but is the potential for an event. Drilling rig floor is the center stage of all the drilling operations and it is most susceptible to accidents. Safety precaution with utmost care is required to be taken during drilling as per the prevailing regulations and practices so that accidents can be avoided. Due to advancement in technology, number of equipment's has been developed over a period to cater the need of smooth operation on a rig floor. Various standards are required to be referred to cover the variety of equipment's used for safe operation in drilling and it is desirable to use a properly prepared manual for occupational safety while working or drilling over a rig. It may, however, be noted that well testing and production testing of hydrocarbons also require proper analysis of hazards involved in production testing operations and preparation of an appropriate emergency control plan (ECP).

Hydrocarbon operations are generally hazardous in nature by virtue of intrinsic chemical properties of hydrocarbons or their temperature or pressure of operation or a combination of them. Fire, explosion, hazardous release or a combination of these are the hazard associated with hydrocarbon operations.
The *problem statement* of this work is that the petrochemicals drilling operation is highly correlated with health and safety risks because of improper handling and safety precautions and measures. Most of the major hazardous incidents in past ten years from 2012 - 2022 have been occurred because of insufficient well control operation which had caused large number of casualties and property damage. The aim of this research study is to define and evaluate the best practices for reducing chemical exposures and subsequent health effects through a risk-based management (RBM) process. This work is useful for plant operator, drilling personnel, managers, health, safety and environment (HSE) managers, drilling fluid specialists, rig-site medical staff, and occupational health and hygiene professionals (OHHP).

2.0 BACKGROUND LITERATURES

Drilling rig is an integrated system that drills wells, such as oil or water wells, or holes for piling and other construction purposes, into the earths subsurface. Drilling rigs can be massive structures housing equipment used to drill water wells, oil wells, or natural gas extraction wells, or they can be small enough to be moved manually by one person usually called auger. It can sample subsurface mineral deposits, test rock, soil and groundwater physical properties, and also can be used to install sub-surface fabrications, such as underground utilities, instrumentation, tunnels or wells. Drilling rigs can be mobile equipment mounted on trucks, tracks or trailers, or more permanent land or marine-based structures (such as oil platforms, commonly called 'offshore oil rigs' even if they don't contain a drilling rig). The term 'rig' therefore generally refers to the complex equipment that is used to penetrate the surface of the earth's crust *(Asad and Hassan 2017).* A typical oil and gas process rig plant is depicted in Figure 1.

Table 1 summary review of previous investigations

Author(s)	Research Investigation and Capacity Frame	Research Benefits/Product Investigated	Study Remarks/Research gaps
Asad et al., (2014)	Descriptive statistical approach, quantitative data analysis, what-if analysis was used in this research.	Identify the potential hazards associated with hazardous well control activities at Malaysian, Saudi Arabian and Pakistani oil and gas industries.	Identification of suitable hazard controls for other drilling and production industries and regions for accident prevention and safety and health management.
Asad and Hassan (2017)	A systematic literature review based on life threatening disasters and	Development of KBES with hazard controlling factors and measures for	Proper analysis on dynamic hazard was not carryout.

	potential hazards associated with onshore and offshore oil and gas drilling operation around the globe since 18 years.	contracting health and safety risk in oil and gas drilling process: a conceptual action plan.	
Jian et al., 2022	An Integrated framework of safety performance evaluation for oil and gas production plants: Application to a petroleum transportation station.	High integral framework to identify measures to prevent leakages and improve on safety standard.	Advanced safety management of tank farms need urgent attention, in order to prevent hazards and catastrophic accidents.

Figure 1: An offshore rig plant

In the 1970s, outside of the oil and gas industry, roller bits using mud circulation were replaced by the first pneumatic reciprocating piston Reverse Circulation (RC) drills, and became essentially obsolete for most shallow drilling. Currently, it is only used in certain situations where rocks preclude other methods. RC drilling proved much faster and more efficient, and continues to improve with better metallurgy, deriving harder, more durable bits, and compressors delivering higher air pressures at higher volumes, enabling deeper and faster penetration. Diamond drilling has remained essentially unchanged since its inception (Asad et al., 2014).

2.1 Drilling Risk Identification

Drilling operation is a complex activity and it is subject to a variety of hazards, some of which are location and activity dependent. Thus, the drilling risk management should be commensurate with the site, water depth, available information and complexity of the situation. Hazards are placed in this hierarchical structure as they are identified, and it is organized by source (category), consequently, the total risk exposure can be better visualized, and the risk mitigation plans are more easily implemented. This process produces a catalogue of all possible hazards, termed Risk Influencing Factors (RIFs), which must be filtered, since there is no need to take forward hazards of lesser importance for more detail study.

2.2 Hazard Structuring

Hazard identification, or scenario building, is the first step in determining hazards affecting an activity. Identification also enable to documenting characteristics of hazards. Each hazard is a risk influencing factor, which is grouped under headings and subheadings. In risk analysis we envision what could go wrong, how often and what are the consequences if something goes wrong. For this we need to list all possible events or "scenarios". This approach produces triplets' equation (1), that is,

$$(S_i, L_i, C_i);\ i = 1, 2, \ldots\ldots N \quad (1)$$

Where, S_i is the scenario i and L_i is the likelihood of scenario i. Risk is defined as a function of these triplets, i.e.

$$R = \{(S_i, L_i, C_i)\} \quad (2)$$

This equation is generally simplified as

$$R = \sum_{i}^{N} Li * Ci \quad (3)$$

Where, C_i is the consequence of scenario i

The set of triplets should be complete, namely it should include every possible scenarios, or at least those which are important. In fact, it is not obvious how even near completeness can be achieved (2). Moreover, the set of scenarios in (2) must not overlap. This method generates a comprehensive list of all sources of hazards, i.e., categories of risks, in the order of dozens of entries. Consequently, there is a need to discriminate among these sources. Figure 2 represent the programming method flowsheet for safety assessment used for oil and gas rig plant (Jian et al., 2022).

2.3 Risk Filtering

Filtering is performed at the sub-category level, to eliminate overlapping and less relevant RIFs. RIFs are filtered according to their perceived levels of likelihood and consequences. Filtering is achieved on the bases of expert experience and knowledge, as well as function, and operation of the drilling system being assessed. This activity often substantially reduces the number of RIFs. In this, the joint contributions of two different types of information-the likelihood of what can go wrong and the associated consequences-are estimated on the basis of the available evidence and engineering judgment. The evidence for taking forward a hazard for detailed studies can be determined by answering questions noted in Table 1.

Table 1: Questionnaire for sifting hazards

Question	Meaning
Is this hazard detectable	The system has redundant means of detecting and arresting a hazard before harm could occur.
Is this hazard controllable	There are controls by which it is possible to take action or make an adjustment to prevent harm.
Is there multiple paths to failure	There are multiple and possibly unknown ways for events to cause harm, e.g. by circumventing safety controls.
Is the effect irreversibility	The system cannot be returned to the normal condition once the adverse event occurred.
Is the event duration of long enough to cause harm	Prolonged events with adverse consequence
Would the event trigger a cascading event	The event can trigger a cascading events which easily and rapidly propagate which cannot be contained
Does the event originate from external sources?	Risk due to external interferences with little or no control over them.
Can the system take more wear and tear	Would further degradation lead to degraded performance or accident
Does the machine human interface	Interfaces among diverse subsystems (e.g., human, software and hardware) causing adverse events
Do we understand the complexity?	Too many complexity create a potential for system level behaviour that are not anticipated from a knowledge of components and the laws governing their interactions
Is technology qualified for the task?	Immature or inappropriate technology or other lack of concept qualification

Source: Adopted and modified from (Kaplan et al, 2001)

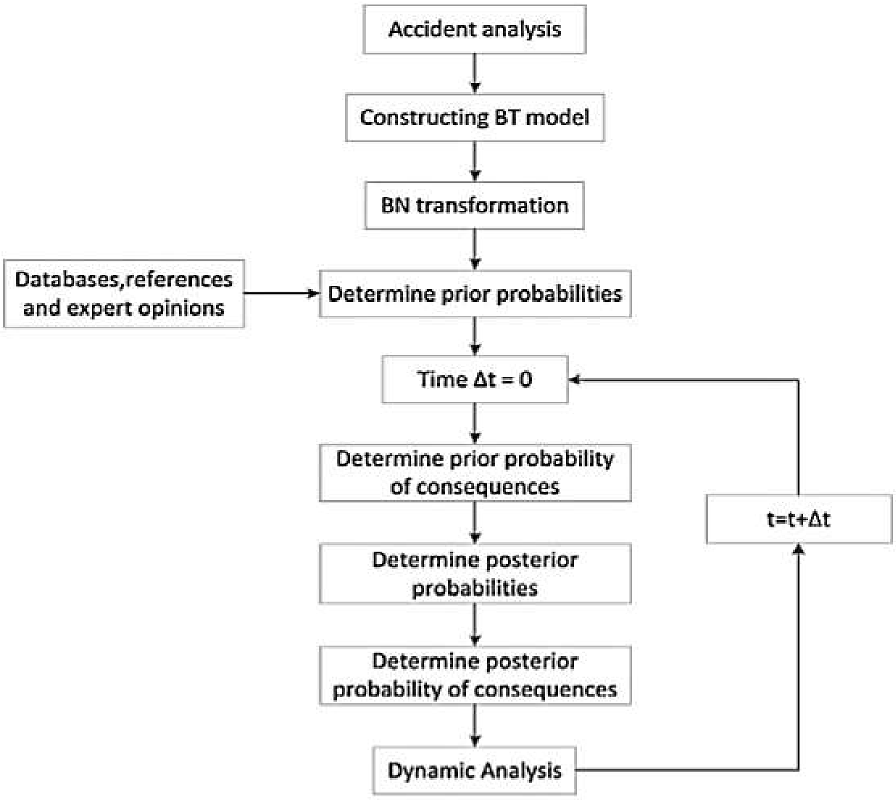

Figure 2: Programming method flowsheet for safety assessment, USA (2019)

Figure 2 represent the programming method flowsheet for safety assessment procedure. The start is based on accident analysis. Databases, references and expert opinions can be introduced at various intervals as the case may be. The time domain from initials determines the loop of the programming calculations. The probabilities of posterior consequences are the sequential steps that characterize the quality of the dynamic analysis. Figure 3 represents the safety cultured elements which is used to improve on the safety regulation of the rig plant systems, and it is well classified to involve six-definite parameters. More details on this research work can be found on Idris and Okaforocha 2021.

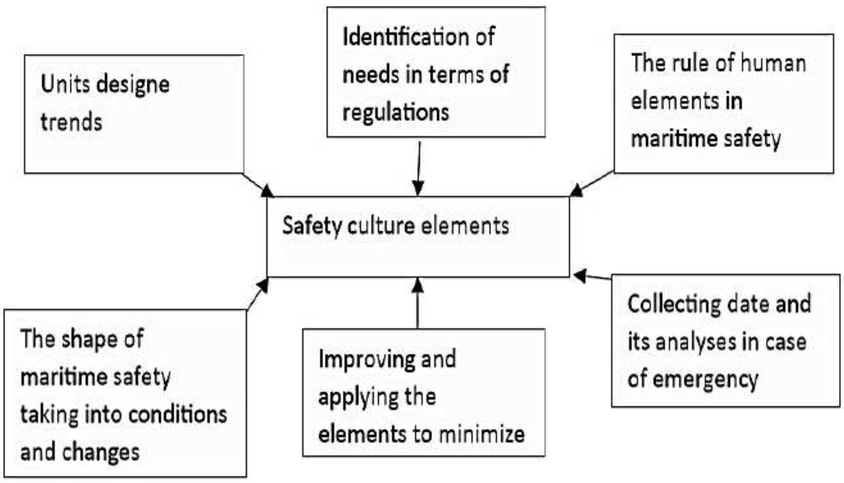

Figure 3: Safety cultured elements

2.4 Drilling Mud Classification

They are classified based on their fluid phase, alkalinity, dispersion and the type of chemicals used.

2.4.1 Dispersed systems

i. Freshwater mud: Low pH mud (7.0 - 9.5) that includes spud, bentonite, natural, and phosphate treated muds, organic mud and organic colloid treated mud. High pH mud example alkaline tannate treated muds are above 9.5 in pH.
ii. Water based drilling mud that represses hydration and dispersion of clay – There are 4 types: high pH lime muds, low pH gypsum, seawater and saturated salt water muds.

2.4.2 Non-Dispersed Systems

i. Low solids mud: These muds contain less than 3–6% solids by volume and weight less than 9.5 lbs. /gal. Most muds of this type are water-based with varying quantities of bentonite and a polymer.
ii. Emulsions: The two types used are oil in water (oil emulsion muds) and water in oil (invert oil emulsion muds).
iii. Oil based mud: Oil based muds contain oil as the continuous phase and water as a contaminant, and not an element in the design of the mud. They typically contain less than 5% (by volume) water. Oil-based muds are usually a mixture of diesel fuel and asphalt. However can be based on produced crude oil and mud.

3.0 MATERIALS AND METHODS

3.1 Materials and Reagents:

The basic materials are the information extracted from the Schlumberger glossaries, One Petro, and PetroWiKi. All other equipment used was obtained from Chemical Process Engineering Laboratory, Department of Chemical Engineering, University of Maiduguri, Nigeria.

3.2 Equipment:

Table 2 presents the equipment used in carrying out the experimental studies.

Table 2 Some of the equipment used in the study

S/No.	Equipment	Name of company and place of manufacture	Equipment type
1.	HP laptop	HP laptop incorporation, USA	Configuration and software installations
2.	Mobile and digital hotspot	Apple mobile incorporation, UK	Multi-functional online provider
3.	HAZOP analysis	HAZOP systems Co. Ltd, USA	Software facilities

3.3 Methods

3.3.1 Adopted Methodology

Critically, focus was placed on precise outcomes of the top event (called ‘study nodes’), one at a time. For each of these study nodes, deviations in the process strictures were examined using the guide words. The guide words ensured that the outcomes were explored in every conceivable way. With this thought, several deviation were established, each of which was well-thought-out carefully, so that their risks (potential causes) and consequences can be identified. Two guide words were used in this study because only two possible outcomes were possible for each of the presented deviations Idris and Okaforocha (2021).

4.0 RESULTS AND DISCUSSIONS

4.1 Results

The results outcomes of the risk assessment tool HAZOP is represented on Table 3.

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Table 3: Summary of HAZOP analysis studies on major rig plant hazard (blowout)

S/No.	Deviation	Consequences	Guide words		Causes	Actions
			No	Other than		
1.	Fault during abandonment	Kick leading to a possible blowout	N/A	Formation fluid invasion into wellbore (kick) leading to a blowout	Poor abandonment procedure	Bottom hole cement, drilling fluid column, manual activation of BOP
2.	Cement seal fails	Kick leading to a possible blowout	N/A	Formation fluid invasion into wellbore (kick) leading to a blowout	Poor slurry design, improper hole cleaning prior to cementing, poor cement job, insufficient slurry volume	Correction of cement formulation, integrity test, use of drilling fluid column, manual BOP activation
3.	Inadequate fluid column	Kick leading to a possible blowout	N/A	Formation fluid invasion into wellbore (kick) leading to a blowout	ECD loss, surface drilling fluid dilution, cement density reduction, drilling process releasing formation fluids, weighting material movement from mud cleaning equipment, drilled cuttings or mud weighting material settling	Correct mud density, well control procedures, use of drilling fluid column, manual activation of BOP
4.	BOP fails when needed	Kick leading to a possible blowout	N/A	Blowout	Failure to self-activate, late response of drilling crew to activate BOP	Knowing the design limitations identified in a hazard analysis, routine inspection and maintenance, drilling crew vigilance and response, manual activation of BOP

4.2 Discussion of Results

Some contaminant and their measures are summarized as follows:

4.2.1 Carbonate/Bicarbonate

Carbonate and bicarbonate ions form one of the most unrecognized forms of contaminants as its gradual development will result in increasing yield point and gel strength. It might be falsely diagnosed as increased solids but the use of thinners will have no effect in treatment.

Pm

Pm stands for 'phenolphthalein end point of the mud' and it specifies extents of Potassium Hydroxide (KOH), caustic soda and cement in the water base mud. The Pm states to the amount of acid needed to decrease the pH of mud to 8.3. The Pm test comprises the effect of both dissolved and non-dissolved alkalis and salts in drilling fluid.

Pf

Pf stands for the phenolphthalein alkalinity of the mud filtrate. Pf is unlike the Pm as it tests the effect of only dissolved bases and salts. However, Pm includes the effect of both dissolved and non-dissolved alkalis and salts in drilling mud.

Mf

Mf stands for the methyl orange alkalinity end point of mud filtrate and the definition of the methyl orange alkalinity is the amount acid used to reduce the pH to 4.3. According to the API test, Pm, Pf and Mf are shown in a daily mud report and all the figures are reported in cubic centimeters of 0.02N sulfuric acid per cubic centimeter of drilling fluid sample.
Pf and Mf are based on the mud filtrate tests that will help people know about ions in the drilling mud.
There are three cases regarding Pf and Mf.

a) **First case**: Pf and Mf are similar in value to each other. It indicates that the ions (hydroxyl ions) are the main contributor to the mud alkalinity.
b) **Second case**: If Pf is low but the Mf is high, it indicates that bicarbonate ions are in the mud.
c) **Third case**: if both figures (Pf and Mf) are high, it means that carbonate ions are in the mud system.

Treatment

Add caustic soda to increase pH to the range 9.5 to 10, later add lime and gypsum to overcome contamination.

4.2.2 Cement Contamination

Cement is the most occurring type of contamination as it is found in every drilling process. Calcium hydroxide is the source of contamination and it may cause higher fluid loss, higher PH and thickening of bentonite based drilling fluid (flocculation of the bentonite clay).
Pre-treatment level determines the severity of the problem as following;

a) Lignosulphocate high treated system, viscosity will drop as clay will not be dispersed rather it will be flocculated state.
b) In polymer treated mud system, precipitation of polymers will occur due to the increase of pH and calcium concentration caused by the contamination.

Sources of Contamination

a) Drilling green cement rich section

b) Adopting poor placement job

Diagnosis

Main indications were:

a) Higher pH
b) Increased calcium concentration

Treatment

- Pretreating mud with sodium bicarbonate with concentration of 1.0 lb./bbl.
- In severe cases of contamination, we use sodium bicarbonate at rate of 0.15 lb./bbl. for each 100 ppm calcium.
- In some cases it's economically beneficial to displace contaminated mud with new mud. This is familiar when drilling formation which contains high quantities of cement.

Using sea water to drill cement section is offshore rigs could be an option as well as using formation water in onshore sites

4.2.3 Calcium Sulphate

Flocculation of bentonite based mud will be resulted from the contamination causing an increase in fluid penetration to the formation and increasing yield point.

Sources of Contamination

Mostly while drilling Anhydrite

Diagnosis

- Increase in calcium filtration
- Decreased pH

Treatment

- Add soda ash with rate 0.116lb/bbl. for every 100ppm calcium
- Lignosulphonate treatment might be needed to control viscosity and filtration.

4.2.4 Salt

High salt content in bentonite based fluid may cause high gel strength and fluid loss

Polymer systems can overcome salt contamination. However, polymer concentration will depend on that of salt.

Sources of Salt

- Salt dome
- Salt water aquifers

Diagnosis

Increased chlorides

Decreased pH

Treatment

In most cases, the only treatment for salt contamination is dilution with water.

Salt content in bentonite based fluid may cause high gel strength and fluid loss

Polymer systems can overcome salt contamination. However, polymer concentration will depend on that of salt.

Table 3 shows that, the 'guide word' HAZOP was used in the HAZOP analysis of the blowout. Focus was placed on the precise outcomes of the top event (called 'study nodes'), one at a time. For each of these study nodes, deviations in the process parameters were examined using the 'guide words'. The guide words ensured that the outcomes were explored in every conceivable way. With this thought, several deviations were established, each of which was considered carefully so that their potential causes and consequences was identified. Two guide words were used in this study because only two possible outcomes were possible for each of the presented deviation. One common hazard in rig plants is the potential for fluid contaminations this can occur when fluid used in the drilling process, such as drilling mud, come into contact with contaminant such as carbonate/bicarbonate, cement, calcium sulphate, salt etc., (Shah et al., 2010).
In this report, there was not analysis done on pressure gauge values due to malfunction of the pressure valve on the system availability. However, temperatures were manually taken daily by hand deep method into the tanks due to malfunction of the automatic temperature level indicator system. A temperature range for fourteen months is presented below as locally recorded by the operators as shown in Table 4.

Table 4: Temperature values taken at average range for 14 months from 2021 to 2022

S/No.	Month	Temperature range(^oC)	Mean Temperature (^oC)
1.	September 2021	20 - 23	21.5
2.	October 2021	20 - 25	22.5
3.	January 2022	25 - 28	26.5
4.	February 2022	25 - 30	27.5
5.	March 2022	28 - 32	30.0
6.	April 2022	30 - 35	32.5
7.	May 2022	30 - 38	34.0
8.	June 2022	35 - 38	36.5
9.	July 2022	35 - 42	38.5
10.	August 2022	20 - 24	22.0
11.	September 2022	20 - 22	21.0
12.	October 2022	22 - 25	23.5
13.	November 2022	25 - 28	26.5
14.	December 2022	20 - 24	22.0

5.0 CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

Within the limit of the experimental errors, the following were concluded from this study:

- That the major event of drilling an oil-well is a blowout, which may lead to a catastrophe and was identify by HAZOP analysis using study node and top event.
- HAZOP risk assessment tools identified that, the causes of a blowout during drilling operation may include; poor abandonment procedure, poor slurry design, improper hole cleaning prior to cementing, poor cementing job, insufficient slurry volume, surface drilling fluid dilution, cement density reduction, drilling process releasing formation fluid, weighing material movement from mud cleaning equipment, drilled cuttings or mud weighing material settling, failure to self-activate, late response to drilling crew to activate blow period, BOP.
- The HAZOP risk assessment tools show that the reviewed controls may deviate during operation, this may include possible fault during abandonment, poor

formulation of cement and mud slurries, cement seal failure, inadequate application of cement hydrostatic pressure in the oil-well column, and BOP failure during kick.
- The HAZOP risk assessment tools show, that all the barriers or controllers may fail to guide the formation fluid invasion into the wellbore (kick) leading to blowout.
- The consequences of a failed control blowout are fire, explosion, fatal loss of lives, and environmental pollution.

5.2 Recommendations

- HAZOP analysis can be used to present valuable information on the threats, consequences and actions that would help mitigate the impacts. However so, the HAZOP is best utilized for futuristic risk assessment.
- To mitigate the risk of fluid contamination, rig plant should have effective measures in place to treat and dispose of these fluids safely. This may include using separators to separate the fluids from solid materials, using specialized treatment systems to neutralize or remove harmful chemicals, and disposing of the fluids in an environmentally responsible manner.
- Training workers on the proper handling and disposal of fluids, implementing robust safety procedures and protocols, and regularly monitoring and testing the fluids to ensure they are being handled and treated properly.
- It is also important to have emergency response plans in place in case of accidental releases or spills of fluids, to minimize the impact on the environment and protect the health and safety of workers and the surrounding community.

Abbreviations:

BOP	*Blowout process*
ECD	*Emergency control development*
ECP	*Emergency control plan*
FMEA	*Failure mode effect analysis*
HAZOP	*Hazard analysis and operability studies*
HSE	*Health and safety executive*
KBES	*Hazard base evaluation systems*
OHHP	*Occupational health and hygiene professionals*
OSHA	*Occupational and safety health administration*
RBM	*Risk based management*
RC	*Reverse circulation drills*
RIFs	*Risk Influencing Factors*

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