DACC
DRILLING AND COMPLETION COMMITTEE

IRP 14:
Non Water Based Drilling Fluid

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for the Canadian Oil and Gas Industry
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14.0 Preface

14.0.1 Purpose

IRP 14 Non Water Based Drilling Fluid is designed to provide critical information to assist those responsible for controlling the risks associated with the use and handling of non water based drilling fluid. This IRP provides introductory information on the makeup and use of non water based drilling fluid. It then offers both general and specific recommendations to minimize the hazards and control the risks presented by these fluids. These recommendations represent a useful starting point for companies to develop their own comprehensive strategies for managing the health and safety risks posed by operations that use or are conducted in the vicinity of non water based fluids. Both health and safety as well as operation personnel may also find IRP 14 serves as a useful educational tool on the use and risk of non water based drilling fluid.

14.0.2 Audience

IRP 14 was written with multiple audiences in mind. It addresses the concerns of health and safety specialists in the industry. It also takes into consideration the interests of operational personnel. This would include individuals involved in the design of drilling operations and drilling fluid programs, anyone managing or supervising drilling operations on location, as well as frontline supervisors and workers.

14.0.3 Scope and Limitations

The committee set out for itself the following scope and limitations when developing this revision of IRP 14:

- Only non water based drilling fluid was considered. Water based fluids are touched upon at various points, but the focus is solely on non water based fluids.
- Only lease-based operations were considered. This includes transfer of the fluid upon arrival on the site, its use in drilling operations, its effect on various tasks and personnel working onsite during a drilling operation, its transfer offsite and rig out.
- When engaging the topic of risk management and control, all participants from planners, through implementation personnel and workers were considered as carrying some form of responsibility.

14.0.4 Revision Process

IRPs are developed by the Drilling and Completions Committee (DACC) with the involvement of both the upstream petroleum industry and relevant regulators. Enform acts as administrator and publisher.

The DACC will formally review the need to revise IRP 14 five years after publication.

Technical issues brought forward to the DACC, as well as scheduled review dates, can trigger a re-evaluation and review of this IRP in whole or in part. For details on the IRP creation and revisions process, visit the Enform website at www.enform.ca.

14.0.5 Sanction

The following organizations will be asked to sanction this document:

Canadian Association of Oilwell Drilling Contractors (CAODC)

Canadian Association of Petroleum Producers (CAPP)

Petroleum Services Association of Canada (PSAC)

Small Explorers & Producers Association of Canada (SEPAC)

14.0.6 Acknowledgements

The following individuals helped develop this edition of IRP 14 through a subcommittee of DACC.

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14.0.7 Range of Obligations

Throughout this document the terms ‘must’, ‘shall’, ‘should’, ‘may’, and ‘can’ are used as indicated below:

Table 2. Range of Obligation

Term	Usage
Must	A specific or general regulatory and/or legal requirement that must be followed.
Shall	An accepted industry practice or provision that the reader is obliged to satisfy to comply with this IRP
Should	A recommendation or action that is advised
May	An option or action that is permissible within the limits of the IRP
Can	Possibility or capability

14.0.8 Copyright Permissions

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Table 3. Copyright Permissions

Copyrighted Information	Used in	Permission from
International Petroleum Industry Environmental Conservation Association (IPIECA) and International Association of Oil & Gas Producers (OGP), *Drilling fluids and health risk management: A guide for drilling personnel, managers and health professionals in the oil and gas industry* (OGP Report Number 396, 2009)	Table 4. Definitions for Group I, II, & III drilling fluids;	OGP/IPIECA

14.0.9 Definitions

Non Water Based Drilling Fluid: This is the default term used throughout IRP 14 to refer to drilling fluids with a hydrocarbon rather than water base fluid. It is equivalent to the expression “Non Aqueous Drilling Fluid” (NAF). It is also sometimes loosely referred to as “invert” and would include fluids also referred to as Oil Based Mud (OBM) and Synthetic Based Mud (SBM).

14.1 Background on Drilling Fluids

The subject matter of IRP 14 lends itself to two audiences.

On the one hand are the health and safety professionals who work within or alongside the upstream Oil and Gas Industry. Their expertise lies in recognizing and analyzing the health and safety concerns associated with the chemicals one might find on a lease site during drilling operations. They see chemicals and the risk of chemical exposure to workers as a problem to be solved.

On the other hand are the operational professionals who plan and carry out the tasks required to drill, recover and transport hydrocarbons. Their expertise lies in analyzing and addressing the requirements of drilling, completing, and servicing operations. They see various wellbore chemicals as a solution to their problems.

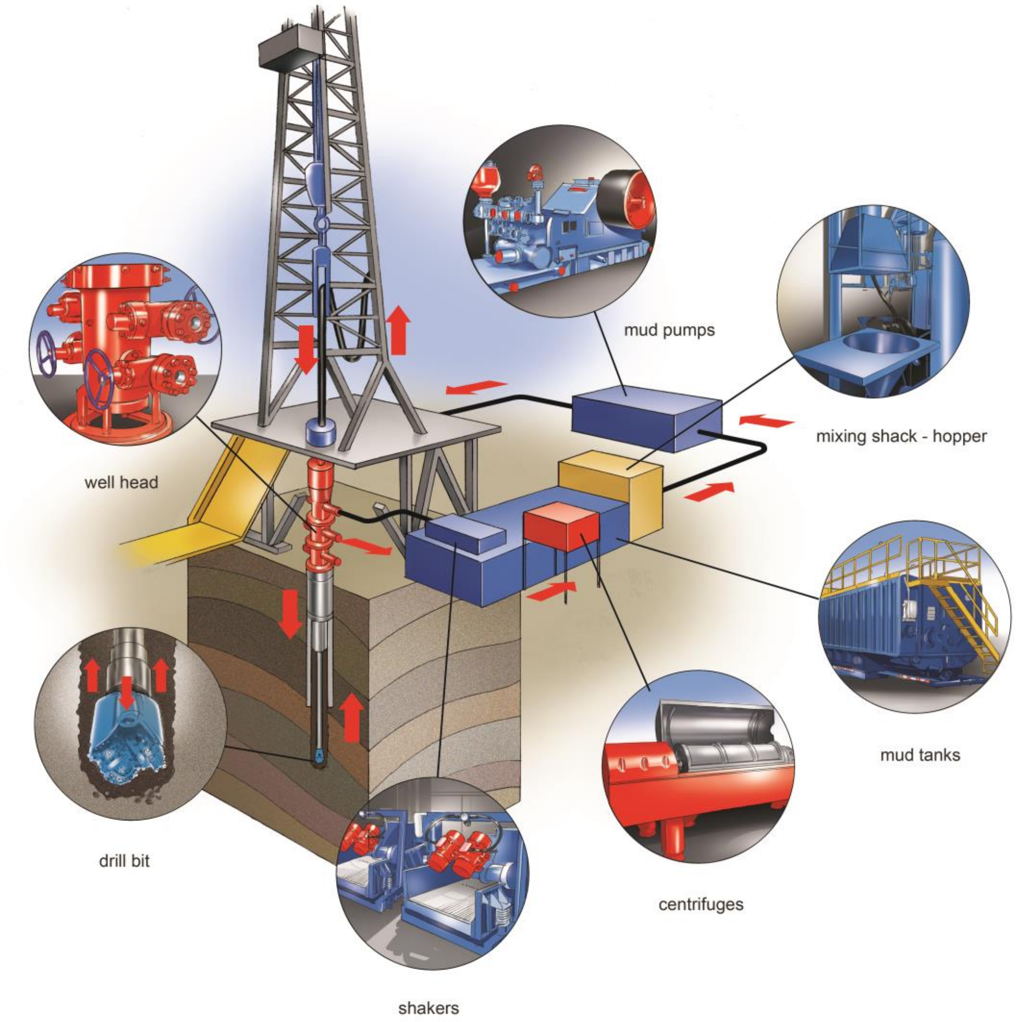
More effective chemical management, and especially more effective management of the risks of non water based drilling fluids, will require these two audiences to understand each other's perspective. "Safe for workers" can complement and be built into "effective and efficient" operations when these two types of professionals communicate effectively and work collaboratively with each other. To that end, there are two introductory backgrounds offered:

- An introduction to the “what” and “why” of drilling fluids from an operational standpoint for the benefit of health and safety professionals who may require this background knowledge.
- An introduction to the concerns of health and safety professionals for the benefit of operational professionals who may require this background knowledge or simply need reminding of the perspective they bring to the table.

14.1.1 An Introduction to Drilling Fluids for Health and Safety Professionals

Drilling fluids are a necessity in oil and gas drilling operations. During most active drilling operations, drilling fluid is continuously circulated in and out of the wellbore. Historically, drilling fluid was simply water. However as drilling operations became more complex, other qualities were required of the drilling fluid. As a result, additives multiplied and even the base fluid changed in some cases from wate to hydrocarbons. To fully appreciate the why of these additives and the choice in base fluid, it is necessary to understand the functions that drilling fluid fulfills.

Figure 1. Fluid Circulation System During Drilling Operations



- **Well Control**

Drilling fluid serves as a key well control barrier during drilling operations. The heavy weight of the column of drilling fluid in the wellbore counters possible downhole pressures. If or when the drilling operation encounters formations that are loaded with high pressure liquids or gas, the weight of the fluid protects surface workers and equipment from an influx of these fluids.

By preventing the flow of formation fluids into the wellbore, the hydrostatic pressure of the drilling fluids also protects the wellbore walls from collapsing as a result of a free flow of formation liquids or gases into the wellbore.

Typically a combination of an added weighting agent along with drill solids ensures the drilling fluid provides sufficient hydrostatic pressure to control the well and protect the wellbore.

- **Cuttings Removal**

During drilling operations, the drilling fluid is pumped down the drill string and out through the drill bit at the bottom of the hole. As the drill bit produces cuttings, these are circulated back up the wellbore to the surface via the annulus (the space between the drill string and the wellbore wall or casing). To fulfill this function, the drilling fluid must have enough viscosity and velocity to carry the cuttings back to the surface. Clay and polymers are typically used to create an adequate level of viscosity.

At the surface, the cuttings are initially screened from the fluid using shale shakers. These devices use a vibrating wire-cloth screen to separate cuttings from the drilling fluid.

Typically the rig crew will be involved in tasks related to capturing samples of the cuttings. These cuttings samples with then be handled and examined by a geologist to determine the downhole formations. The drilling fluid engineer (sometime referred to as the “mud man”) or mud logger may also be involved in the capture and monitoring of samples. Their interest lies in analyzing the drilling fluid properties to maximize its effectiveness as drilling continues or special operations are required.

Additional solids control equipment may be applied to the fluid after its journey through the shale shakers. This can include hydrocyclone devices (e.g., desilters and desanders) and centrifuges. A series of mud tanks capture the drilling fluid following these processes. In most cases these steel containers have an open top. From there the fluid is drawn into large drilling fluid pumps and recirculated back downhole under great pressure.

- **Cuttings Suspension**

If it is necessary for drilling fluid circulation to stop, the instantaneous gel strength of the drilling fluid must be sufficient to hold the cuttings in suspension through various deviations of the wellbore (vertical and horizontal sections) and for a reasonable period of time. Additives that affect the rheology are used to create sufficient viscosity (or “thickness”) to suspend the cuttings until pumping operations resume.

- **Hydraulic Power**

Drilling fluid exiting the drill string through drill bit nozzles provides hydraulic power to run the mud motor (rotating the bit independent of the drill string) enhancing the drill’s rate of penetration.

High viscosity and friction can create pressure loss in the drill string or in the wellbore, affecting the amount of hydraulic power available to the drilling assembly. Fluid with particular rheological characteristics and specific additives may be chosen to lower the friction (higher lubricity coefficients) and reduce the viscosity of the drilling fluid while it is in circulation.

- **Cooling and Lubricating the Drill String and Bit**

Another function of the drilling fluid is to provide a means to cool and lubricate the drill bit and string during the course of drilling operations. As drilling depth and/or the angle increases, there is greater torque placed on the BHA (bottom hole assembly), increasing the importance of this function.

- **Filtration and Filter Cake**

Drilling operations also face the challenge of minimizing the amount of drilling fluid lost to the formation while drilling. When drilling in a formation that is fractured, porous or highly permeable, the drilling fluid that passes into the formation is known as the filtrate. It leaves behind a layer known as filter cake. Cake thickness, toughness, lubricity and permeability are important properties because the filter cake can cause a number of problems such as stuck pipe. A correctly formed, easily removable filter cake is desirable. Once formed, filter cake isolates the formation from drilling fluid. This has two benefits. First, it prevents a loss in pressure that may result with drilling fluid migrating out of the wellbore into the formation. Second, it also prevents deep penetration of filtrate into the reservoir formation which can create wellbore instability as well as reduce oil and gas production. Careful engineering and additives are required to control filtration and the formation of the filter cake.

- **Formation Stability and the Introduction of Hydrocarbon Based Drilling Fluids**

Whenever the drilling fluid interacts with the formation, there is a danger of formation damage as a result of the interaction. Water based fluids interact with shale formations very easily and readily cause unstable wellbores and very difficult drilling conditions.

Beginning in the 1960's, this problem was increasingly addressed with the introduction of hydrocarbon based drilling fluids. Oil had been added to water for lubricity in the past. Now with oil as the base and water added, one had an inverted emulsion of water in oil—hence the name "invert". Since then, changes to drilling practices have contributed to an increasing use of hydrocarbon based drilling fluids, including:

- Drilling longer stretches before lining the borehole with steel casing and cement creating more extensive exposure of the wellbore formation to fluids.
- Increased drilling in formations prone to damage from water based fluids (e.g., shale plays containing clays).

- Higher drill torque and accompanying higher temperatures that are more easily managed with the lower friction and higher temperature range afforded by hydrocarbon based fluids.

In many cases, it is the nature of the formation that is the deciding factor in using hydrocarbon based fluids.

14.1.2 An Introduction to Drilling Fluids from a Health and Safety Perspective for Operational Managers

From a health and safety standpoint, drilling fluids are not measured on the basis of how effectively they perform their task in making well drilling economically viable or profitable. When it comes to non water based fluids with additives x, y, and z, health and safety professionals raise concerns that are central to their profession:

- What are all the individual chemicals in the fluid being delivered to a drilling location?
- What are the inherent short term, midterm, and/or long term health effects of this chemical or chemical mixture on humans if they are exposed to the chemical?
- What are the routes of exposures that are harmful? Inhalation? Skin contact? Swallowing? Eye contact?
- How are the operations configured and where in the operation can human exposure take place? And back to "what type of exposure"?
- How do the workers function in these operations? What are the expected duration and levels of exposure in their particular tasks?
- What other types of operational hazards apart from human exposure and related health concerns might there be? Flammability? Degradation of safety components or devices? Other related workplace hazards?
- How will these risks be monitored and hazards eliminated and/or controlled?

Operational professionals and personnel see base fluids and additives as problem-solving. It is critical that they also understand why health and safety professionals see these as the problem to be solved. Typically, the most effective means of addressing and controlling chemical exposure and other related chemical risks lies in the hands of operational personnel. The health and safety of personnel that must work with and around drilling fluid and its associated chemicals is dependent on the decisions of project engineers, planners and managers who may never be on the worksite. Likewise, the decisions and actions of onsite managers, supervisors, and other workers will also have a bearing on the type and level of exposure these workers will face. Formal chemical risk management systems and an informal culture of chemical handling safety built into the planning and execution of operations are essential to alleviate the concerns health and safety professionals bring to the table.

14.2 Drilling Fluid Composition

While the concern of IRP 14 is non water based fluids, it is important to understand the make-up of drilling fluids whether water based or non water based. Understanding the distinction between the two is critical in terms of a broad chemical management plan. Each fluid system has an optimal role within drilling operations and each accomplish this with a slightly different set of additives.

14.2.1 Base and Additives

Drilling fluids are made up of a liquid base and a series of chemical additives. In the case of non water based fluids, the base liquid typically makes up 80-95% of the fluid by volume with the rest of the fluid made up of water and a series of chemical additives. The choice of base fluid is typically determined by the density requirements for the formations that the operation must drill through. For example, shale formations contain clays that can swell, slough and stick when exposed to water. As such, non water based fluids carry an inherent advantage due to their inhibitive qualities in these formations. Whatever the choice of base fluid, additives are essential to arrive at a drilling fluid that fulfills the roles outlined in 14.1.1 An Introduction to Drilling Fluids for Health and Safety Professionals.

- **Density**

Sufficient fluid density is required to put pressure on the formation downhole. This prevents high pressure formation liquids or gases from flowing into the wellbore, potentially damaging the wellbore and creating the potential for a kick or blowout. Typically, the higher the downhole pressure encountered, the greater the fluid density required.

- **Viscosity**

Drilling fluid viscosity (or “thickness”) must be such that it can successfully suspend and remove cuttings during drilling operations. Increasing drilling fluid weight and viscosity is most frequently accomplished by adding barite (barium sulphate) or calcite (calcium carbonate)—typically the single largest additive in the drilling fluid mixture. The viscosity of the fluid affects pump pressures and must be kept within programmed tolerances to achieve the static and dynamic requirements for the wellbore as well as ensure optimal operation of downhole tools.

- **Fluid Loss Control**

Additives are also used to enhance the fluid's filter cake properties in multiple ways. This layer is designed to adhere to the walls of the wellbore primarily to minimize the drilling fluid from interacting with the reactive formations being drilled.

- **Bacteria and Oxidization Control**

Water based fluids often require additives for bacteria and oxidization control. Biocides or bactericides control sulfate-reducing, slime-forming, iron-oxidizing, and other types of bacteria that may degrade a water-based fluid and render it less effective. They may also be used along with oxygen scavengers and other corrosion inhibitors to prevent oxidization in the wellbore which can damage the formation and subsequent production.

- **H_2S Scavengers**

Drilling fluid may also be pre-treated or actively treated during operations with chemicals that serve as H_2S scavengers when drilling through formations with H_2S bearing zones.

- **Salinity**

In a non water based fluid system, a high-salinity water phase is essential in preventing shales from hydrating, swelling, and sloughing. Calcium Chloride is often used to maintain the salinity of the water phase in the fluid but it is highly caustic and exothermic in nature.

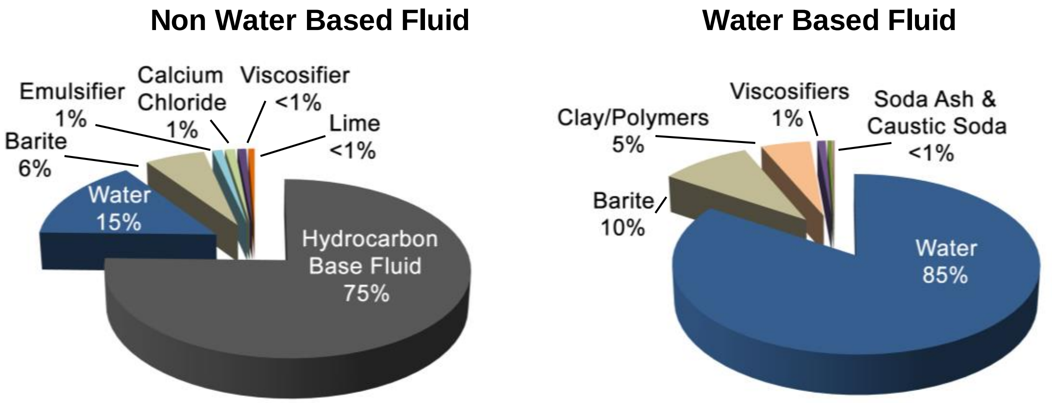
14.2.2 Adjusting Composition

Drilling fluid rheology is regularly adjusted over the course of a drilling operation. This necessitates ongoing mud testing and the deployment of chemical additives.

Operations that use a non water based drilling fluid actually begin initially with a water based fluid system. After drilling has passed ground water sources and these water sources are protected behind casing and cement, the system is displaced and drilling operations with non water based fluids begins.

The following pie charts illustrate the average chemical make-up of water-based and non water based drilling fluids by volume.

Figure 2. Examples of composition of drilling fluid by volume

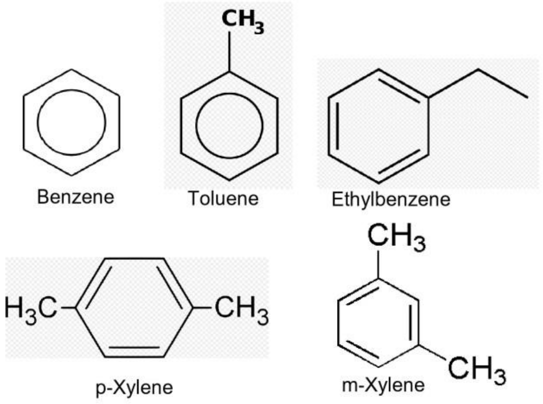

Non Water Based Fluid **Water Based Fluid**

(Approximate volumes for illustration purposes, percentages will vary based on drilling program requirements)

14.2.3 Base Oils in Non Water Based Drilling Fluid

A variety of base oils have been and continue to be used in the makeup of non water based drilling fluid. Base oils range from various commercial distillates to highly refined paraffins. The properties and specific chemical composition of these oils depends on the original crude stock and the refining process used to produce them. Selecting a base oil for optimal drilling performance is a potentially complex process that lies outside the scope of this IRP. In terms of managing the health and safety issues related to non water based drilling fluids, total volatility (or the tendency to vapourize) and the specific aromatic components of base oils are key. With that in mind, one way to categorize non water based drilling fluids is by aromatic content.

Figure 3. Aromatics/Arenes: The BTEX molecules



Aromatic hydrocarbons or arenes are hydrocarbons that share the "benzene ring" structure of benzene (C_6H_6), the simplest of the aromatics. They are called aromatics due to their sweet scent. Toluene, ethylbenzene, and xylene are three common derivatives of benzene. As a group (BTEX), these are the most problematic in terms of human exposure. Hydrocarbons formed with more than one benzene ring are called polyaromatic hydrocarbons (PAH) and include such compounds as naphthalene, benzo-anthracene, chrysene, benzo-a-pyrene, and benzo-b-floranthene.

The following table offers the IPIECA / OGP classification that divides non water based drilling fluid into three groups based on the aromatic content of the base fluid.

Table 4. Definitions for Group I, II, & III drilling fluids[1]

Category	Components	Aromatic content
Group I: high-aromatic content fluids	Crude oil, diesel oil, and conventional mineral oil	5-35%
Group II: medium-aromatic content fluids	Low-toxicity mineral oil, distillate products	0.5-5%
Group III: low/negligible aromatic content fluids	Ester, LAO, IO, PAO, linear paraffin and highly processed mineral oil and synthetic oil	<0.5% and PAH lower than 0.001%

14.2.4 Formation Fluids that Potentially Mix with Drilling Fluid

A real challenge in managing downhole chemicals in drilling operations is the fact that as drilling proceeds, formation fluids may begin to mix with the drilling fluid. Drilling operations may proceed through hydrocarbon bearing formations en route to the producing formation. Oil, condensate, and hydrocarbon gases will then be introduced to the circulating drilling fluid as drilling continues. Drilling fluids may also pick up H_2S gases or H_2S contaminated water. Certainly once drilling operations reach the targeted producing zone it is very likely some formation fluid will be introduced to the mix. This unknown is always a challenge in terms of managing the health and safety risks posed by drilling fluids.

This issue of formation fluids creating an unknown composition is further complicated in those operations where drilling fluid used in one operation is then transported and re-used in a subsequent drilling operation. In this case, a drilling crew may be working with a drilling fluid system that already contains an unknown quantity of additives and unknown formation fluids. The recommendations in 14.5.1 Fluid Testing have been crafted with an understanding that drilling fluid may be re-used on multiple drilling operations. The GC C30+ and closed cup flashpoint tests to determine the hydrocarbon content and flashpoint of potentially contaminated fluids are essential in this regard.

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[1] Drawn from *Drilling fluids and health risk management* (London: IPIECA / OGP, 2009), 4.

14.3 Hazards Associated with Non Water Based Drilling Fluid

Non water based fluids used in drilling operations present a risk to both human health and operational safety. Both must be considered in managing and controlling the hazards presented by non water based fluids.

IRP Material Safety Data Sheets (MSDS) information must be available for all workers for the hydrocarbon base and each fluid additive being used or stored at the worksite.

IRP At a minimum, all workers on drilling operations using non water based fluids shall be informed of potential health effects from exposure risks, the potential safety risks, and the required controls applicable to their tasks.

IRP All workers assigned to work with and around non water based drilling fluids should be either trained and/or assessed in their ability to identify, assess, and control the associated health and safety hazards presented by these materials. Operational duties should determine the level and type of competencies required. Appendix 1: Legislation in the Enform Guideline *Controlling Chemical Hazards in the Oil and Gas Industry* provides details on employer requirements across multiple provincial and federal jurisdictions including information and training requirements, hazard controls and written code of practice or exposure control plan requirements. Note also “Appendix 7: Exposure Control Plan Template for Drilling Fluids” in the same guideline copied in this document as Appendix B: Exposure Control Plan (ECP) Template.

14.3.1 Health Effects of Chemical Exposure

The health risks from non water based fluids are both short term and long term and vary considerably depending on a number of factors.

First, there are various types of exposure. How are workers coming in contact with these fluids? Is it on their skin (dermal)? Are they inhaling vapours? Are they inhaling airborne particles? Is it being ingested? Different chemicals present different types of health hazards based on the type of exposure.

Then there is the question of the level of exposure. Is it a small amount over a long period of time? As such, are there health effects from cumulative exposure? Or is it a large amount in short bursts? This may present a different sort of challenge.

As a general rule, where the chemical hazards are immediately apparent, on site supervisors and workers will be far more likely to be proactive in managing and mitigating those risks. If a chemical causes an immediate response, for example burning or irritating the skin or eyes or causing a cough, workers will instinctively protect themselves. Long term effects caused by prolonged, lower level exposures are harder to detect and track. Even once known and understood, it can be challenging to change worksite design and management and worker behaviour because there is no immediate feedback to exposures.

One of the ways to address health risks is to think in terms of types of exposure. What is the point of contact between worker and chemical?

14.3.1.1 Dermal (Skin) Exposure

During drilling operations, it is not uncommon for workers' skin to come in contact with non water based fluids. The most obvious point of contact would be face, hands and forearms. However, if clothing becomes soaked with fluids, there are other points of potential skin contact as well.

- **Dermatitis**

The most common effect of skin contact with non water based fluids is dermatitis, an irritating skin rash that can become quite severe depending on the length of exposure and the individual. The culprit is usually the hydrocarbon base that makes up the largest percentage of the fluid, and more especially the aromatic and C8-C14 paraffin components. As a result, diesel, for example, is more likely to cause dermatitis than a synthetic fluid.

The problem is twofold. Petroleum hydrocarbons will remove natural fat from the skin, leading to the skin initially drying and cracking. This then allows chemical compounds causing dermatitis to more readily penetrate through the skin. With repeated exposures, some workers will develop sensitization to future exposures to similar fluids. In this case, even shorter exposures with lower concentrations may cause a more severe reaction. Fluid additives may also contribute to the problem. Irritants, such as calcium chloride, and corrosives, such as zinc bromide, may increase skin porosity and so increase absorption of the chemical into the skin. Other additives, such as polyamine emulsifier may also have sensitizing properties.

Figure 4. Contact dermatitis from repeated exposure to kerosene

(Photo from CDC/NIOSH)

Other factors that can affect skin absorption rates include the following:

- Concentration of the chemical in the fluid
- Solubility of the chemical in water
- Skin contact area
- Duration of skin contact
- Air temperature
- Humidity
- Level of physical exertion
- The presence of damaged or diseased skin

In addition to dermatitis, exposed workers with poor personal hygiene may suffer from oil acne and folliculitis. Cuts and abrasions on the skin that are not properly addressed and are subject to further exposure can lead to additional complications and infections.

- **Carcinogenicity (Cancer Causing)**

Chemicals absorbed through the skin can contribute to a long-term build up in the body. Chemicals with this potential are typically identified as such in provincial chemical hazard regulations. The BTEX aromatics and especially benzene itself present the greatest concern. Benzene is recognized as a carcinogen and is readily absorbed through the skin. Skin exposure along with inhalation exposure can significantly contribute to a worker’s whole dose of Benzene. As such, the higher aromatic content and PAH components of the Group 1 drilling fluids present a greater risk than the lower aromatic Group 2 or nearly aromatic free Group 3 fluids. Diesel fuel is not designated as carcinogenetic for humans based on skin contact. However, chronic irritation from skin contact with diesel and other hydrocarbons can cause small areas of the skin to thicken. These may eventually form rough wart-like growths that have the potential to become malignant.

14.3.1.2 Inhalation

Workers can be exposed to various chemicals in non water based fluids either by inhaling vapours, aerosol particles (oil mist) and/or dust from mixing chemical additives. In drilling operations, these fluids are often agitated and at heightened temperatures as they circulate through an open tank system and as the drilling fluid flows across shakers. The paraffins, naphthenes and aromatics typically have a lower boiling-point and are at the lighter end of the hydrocarbons. As such they will frequently make up a disproportionately high percentage of the vapours coming from the fluid. The agitation may also atomize an oil based fluid and create an oil mist workers may inhale. Oil mist may also be formed when hydrocarbon vapours rise into the air, cool, and condense. This is a likely scenario especially when heated fluid from downhole encounters sub zero temperatures in open solids control equipment. Oil mist will have a more immediate impact on the respiratory system than vapours. It may cause inflammation of the lung tissue, lipoid granuloma formation, and lipoid pneumonia.

Inhaling excessive hydrocarbon vapor can cause dizziness, fatigue, headaches or nausea. It may also result in irritation and inflammation of the respiratory system. Some workers may have an allergenic type of response to specific substances. Once a person is sensitized, subsequent reactions will occur at a lower concentration. At extremely high concentrations, workers may suffer from hydrocarbon induced neurotoxicity, which includes the headaches, nausea, dizziness, and drowsiness, but may also induce a lack of coordination, problems with attention and memory, difficulty walking, and narcosis. Typically these symptoms are temporary. However, exposure to high levels of n-hexane may result in peripheral nerve damage.

- **Carcinogenicity (Cancer Causing)**

Group 1 and Group 2 fluids may contain trace amounts of benzene or PAHs which can be carcinogenic. More concerning would be benzene contamination of the drilling fluid from producing formations. Aromatics like benzene (with their low vapour pressure) will make up a disproportionate amount of any drilling fluid vapours. While sampling exercises to date have not suggested benzene exposure is a widespread risk during drilling operations with non water based fluids, ongoing vigilance is essential, especially with respect to contamination from formation fluids.

14.3.1.3 Other Routes of Entry

Ingestion of chemical can occur while eating or smoking with contaminated hands. In particular, oral exposure can be significant if workers fail to wash their hands before eating. These exposures can be reduced if workers practice good hand and face hygiene.

Drilling and servicing fluids may also come in contact with the eyes. Typically the hydrocarbon base is minimally irritating to the eyes. However, fluid additives may be irritating or corrosive to the eyes.

14.3.1.4 Occupational Exposure Limits (OELs)

IRP All employers must ensure their workers remain within the occupational exposure limits (OELs) set by the provincial jurisdiction in which they are operating.

> **Note:** Appendix 1: Legislation in the Enform Guideline *Controlling Chemical Hazards in the Oil and Gas Industry* describes legislated OHS requirements across multiple provincial and federal jurisdictions with respect to OELs and what must be done on worksites with potential exposures. In particular, employers should be aware of requirements regarding a documented control plan.

IRP Employers shall take all reasonable steps to eliminate any worker exposure to benzene.

IRP Employers should strive to eliminate any oil mist inhalation exposure hazard.

> **Note:** For industry recommended practices on oil mist monitoring, see the CAPP Guide, *Oil Mist Monitoring Protocol* (December 2004).

Each province has Occupational Health and Safety (OH&S) regulations that set an occupation exposure limit (OEL) for specific chemicals. The American Conference of Governmental Industrial Hygienists (ACGIH) provides similar recommendations in the form of a Threshold Limit Value (TLV). Airborne OELs or TLVs are expressed in terms of the average concentration of the chemical in the air over a short period of time (15 minutes) and over the course of a worker's shift (typically 8 hours). This is known as a time weighted average (TWA). So, for example, in Alberta a worker should never be exposed to more than an average concentration of 8 mg/m^3 of benzene in any 15 minute time slot. If working an 8 hours shift, the average concentration over that time period cannot exceed 1.6 mg/m^3. And in the event it is a 12 hour shift, the limit is 0.8 mg/m^3 (using the ACGIH formula sanctioned in the Alberta OHS Code 2009, 18[1]).

In terms of hydrocarbon OELs, benzene is of the greatest concern and carries the lowest exposure limits because it is designated as a carcinogen. In practice, all reasonable steps should be taken to eliminate any worker exposure to benzene. The other BTEX chemicals (toluene, ethyl benzene, and xylene), trimethyl benzene and naphthalene are also of concern but carrying much higher OELs. OH&S regulations provide a formula to calculate limits for multiple chemical contaminants in the air. However, calculating these limits is typically unnecessary if the employer is applying the total hydrocarbon exposure recommended by ACGIH. With an ACGIH TLV of 100 mg/m^3 for 8 hours and 50 mg/m^3 for 12 hours for total hydrocarbon exposure, as well as the Saskatchewan contamination limit of 150 mg/m^3 for any 15 minute period, other exposure limits should be met. Furthermore, if the employer works toward zero benzene, this will also eliminate the risks of other aromatic exposures. It should be noted that the 12 and 8 hour and 15 minute exposure limits can be exceeded during oil rig operations using non water based drilling fluids. Much depends on the fluid composition and other operational conditions. Individual sensitivities to chemicals may also vary.

The commercial oil base products typically used in drilling and servicing fluids have very low concentration of BTEX and specifically little or no benzene. However, downhole fluids from producing formations or other fluids in storage facilities can contaminate the fluid. This could result in higher than expected concentrations of the chemicals.

While exposure limits for oil mist vary with provincial jurisdictions, they are much lower than that for the total hydrocarbons (THC) vapour. Given this regulatory reality, any inhalation exposure hazard for oil mist needs to be eliminated if at all possible and certainly mitigated as much as possible.

Table 5. Worker airborne exposure limits

*See below for 12 hr shift TWA limit**	Alberta Occupational Exposure Limits		British Columbia Exposure Limits		Saskatchewan Contamination Limits		ACGIH Threshold Limit Value (TLV)		ACGIH & IARC Notations**
	8 hr	**15 min**	**8 hr**	**15 min**	**8 hr**	**15 min**	**8 hr**	**15 min**	
Benzene	0.5 ppm	2.5ppm	.5 ppm	2.5 ppm	***		.5 ppm	2.5 ppm	Skin; A1; 1
	1.6 mg/m^3	8 mg/m^3					1.6 mg/m3	8 mg/m3	
Toluene	50 ppm	--	20 ppm	--	50 ppm	60 ppm	20 ppm	--	Skin; R
	188 mg/m^3	--					75 mg/m^3	--	
Ethyl benzene	100 ppm	125 ppm	20 ppm	--	100 ppm	125 ppm	20 ppm	--	2B
	434 mg/m^3	543 mg/m^3					87 mg/m^3	--	
Xylene(s)	100 ppm	150 ppm	100 ppm	150 ppm	100 ppm	150 ppm	100 ppm	150 ppm	
	434 mg/m^3	651 mg/m^3					434 mg/m^3	651 mg/m^3	
Trimethyl benzene	25 ppm	--	25 ppm	--	25 ppm	30 ppm	25 ppm	--	
	123 mg/m^3	--					123 mg/m^3	--	
Naphthalene	10 ppm	15 ppm	10 ppm	15 ppm	10 ppm	15 ppm	10 ppm	15 ppm	Skin; 2B
	52 mg/m^3	79 mg/m^3					52 mg/m^3	79 mg/m^3	
Diesel (as Total Hydrocarbon [THC] Vapour)									Skin
	100 mg/m^3	--	100 mg/m^3	--	100 mg/m^3	150 mg/m^3	100mg/m^3	--	
Oil mist, mineral *Mineral, mildly refined **Mineral, severely refined									A2*, 1*
	5 mg/m^3	10 mg/m3	0.2 mg/m^3* 1 mg/m^3**	--	5 mg/m^3	10 mg/m3	As low as possible* 5 mg/m^3**		

*Both AB (OH&S Code 18[1]) and BC (OHS Reg. 5.50[1]) offer a calculation to adjust the 8 hour TWA to a longer shift length. The 12 hour shift TWA is easily calculated as it is simply half the 8 hour TWA (8hr TWA ÷ 2).

**ACGIH Notations in this table include “Skin” (substances that contribute significantly to the overall exposure by the skin route), “A1” (confirmed human carcinogen), “R” (reproductive toxin), and IARC Notations include “1” (agent is carcinogenic to humans) and “2B” (agent is possibly carcinogenic to humans).

***Benzene appears only in Table 20 and is subject to Sec. 306 and 311 which effectively challenges employers to achieve zero exposures through engineering and PPE controls.

14.3.2 Operational Hazards

Non water based fluids used in drilling and well servicing operations not only present a risk to human health as a result of exposure, they present other operation hazards that should be identified and controlled. In addition to health hazards from oil, mist, and vapour exposures, operational hazards that should be considered include: the combustibility/flammability of oil based fluids; elastomer degradation in well control equipment; slippery surfaces created by the fluid; and late kick detection when using non water based fluid.

14.3.2.1 Flammability/Combustibility

IRP Flammable liquids shall not be used in drilling operations with a conventional, open circulation system.

IRP Combustible liquids may be used in drilling operations with appropriate precautions.

IRP A drilling fluid with a flashpoint below 61°C shall only be used with a fully enclosed circulation system.

IRP In Saskatchewan, a drilling fluid with a flashpoint that is below 61°C must use a fully enclosed circulation system.

IRP The flashpoint of any drilling fluid in use in a conventional, open circulation system shall be higher than the maximum anticipated flow line temperature of the fluid and higher than the maximum anticipated ambient temperature. A safety factor of at least 10°C should be added in order to account for hotter than anticipated downhole temperatures resulting in higher than expected flow line temperatures or a compositional change in the fluid.

IRP Whenever fluid is carried over from one operation to the next, flash point testing shall be carried out as per 14.5.1 Fluid Testing.

The flashpoint of a liquid is the lowest temperature at which the liquid gives off enough vapour to be ignited. Since testing methods and purity of the liquid tested may vary, flashpoint values are intended to be used as a guide only, and not as a definite line between safe and unsafe.

All oil based fluids are combustible and will burn with a large energy release if ignited. As such, all non water based fluids should be regarded as potentially combustible.

WHMIS categorizes liquids as flammable or combustible based on their flash points as per the Controlled Products Regulations (Sections 37-38). Flammable liquids have been designated as having a flash point < 37.8°C (100°F). These will usually ignite and burn easily at normal working temperatures. Fluids with this classification are not recommended as drilling or servicing fluids. Combustible liquids have a flashpoint ≥37.8°C (100°F) and <93.3°C (200°F). Generally speaking, this classification of fluid may be used for drilling operations with appropriate precautions. Note that hot combustible liquids can be as serious a fire hazard as flammable liquids. The higher the flashpoint, the lower the risk of accidental ignition of the fluid.

The *Saskatchewan Energy and Mines Information Guideline GL-99-01* requires a totally enclosed drilling fluid system whenever the flash point of the fluid is < 61°C. It also recommends enclosed systems whenever using refined petroleum hydrocarbon based drilling muds (i.e., distillates and diesel) even in cases where the flash point is >61°C. A similar threshold is used in TDG regulations which includes liquids with a flashpoint ≥60°C in Class 3: Flammable Liquids (2.18 [1.a]). This IRP has adopted the Saskatchewan 61°C flashpoint threshold as a strongly recommended practice across the industry.

Furthermore, this IRP recommends that for open circulation systems the flashpoint of any operational fluid shall always be higher than the maximum flow line temperature anticipated throughout the whole operation or the maximum anticipated ambient temperatures (whichever is greater). Best practice would also dictate that a safety factor should be considered to account for unanticipated fluctuations in flow line temperatures or unanticipated changes in the fluid (typically from an influx of wellbore fluids but also possibly from other fluids added later in the program). The flashpoint of the base fluid is not a sufficient benchmark in determining the flashpoint of any fluid that has been carried over from another project. As per 14.5.1 Fluid Testing these fluids would be subject to a Closed Cup Flash Point test prior to use.

Table 6. Fluid Flash Point: Classification and Usage

WHMIS/CPR 15 Classification	Flash Point (lowest temperature at which liquid gives off enough vapour to ignite)	Usage in Operations
Flammable Liquid (Div 2)	<37.8°C (100°F)	**Shall not be used** in conventional drilling operations (must not in Saskatchewan)
Combustible Liquid (Div 3)	=>37.8°C & <93.3°C (200°F)	May be used in operations **with appropriate precautions and controls** <61°C -- shall not be used in conventional drilling operations (must not in Saskatchewan) (Hot combustible liquids can present the same fire hazard as flammable liquids)

Fluid flash point shall be higher than

- the maximum anticipated flow line temperature of the fluid and
- the maximum anticipated ambient temperature.

A safety factor of 10°C should be added to account for unanticipated fluctuations in flow line temperatures or changes in fluid composition.

Minimizing potential ignition sources is key to the safe management of non water based drilling fluids. This will be discussed in greater detail below under 14.4.2 Safety Hazards Presented by Non Water Based Drilling Fluids.

14.3.2.2 Elastomer Degradation in Well Control Equipment

IRP **When drilling with non water based fluids, all elastomers in the circulation and containment systems shall provide sufficient resistance to any potential elastomer degradation created with the use of non water based fluid.** Where the interaction of base oils or whole fluids with elastomer components is unknown, a test following ASTM D4289-13 should be conducted to establish elastomer performance. Where the Aniline Point is below 65°C, all elastomers in the circulation and containment systems should be reviewed to ensure they are fit for purpose.

IRP **Contractors and rental equipment suppliers shall have a quality control program to ensure elastomer sealing elements for BOP components meet composition, design and performance specifications at all times.**

Well control equipment such as downhole plugs, wellheads, and BOPs often utilize elastomer seals composed of natural or synthetic rubber products. These are more susceptible to degradation from oil base fluids with higher aromatic content. This degradation involves the softening, swelling and permanent alteration of the mechanical properties of the rubber product (tensile, elongation). If well control devices fail, this can create serious well control hazards for on-site drilling and service personnel.

The aniline point of a fluid provides a useful indication of the relative aromatic content of oil based fluids. The aniline point is the temperature at which equal parts of aniline and the oil based fluid are fully miscible (i.e., they become a homogenous solution). Since it is aromatics in the oil that dissolve the aniline with the application of heat, the greater the heat required to create a homogenous solution, the lower the level of existing aromatics in the oil. Since elastomer materials used in seals are degraded by aromatics in the fluid, a known aniline point can help determine the likelihood and rate of elastomer degradation as a result of contact with these fluids. For this reason, choosing a fluid with an aniline point above 65°C where possible may help prevent elastomer degradation.

The relative aromatic content (aniline point) is not the sole determinant of elastomer performance. Other specific fluid constituents under certain service conditions may affect elastomer degradation regardless of whether fluid aniline point is greater than 65°C. Fluids with aniline point somewhat less than 65°C may also be acceptable if appropriate elastomer components that are resistant to degradation from hydrocarbon based fluids are selected and properly maintained. In this case, there should be a systematic review of all elastomers in the circulation system and especially in any containment system to ensure these are all sufficiently resistant to the conditions under which they will operate.

Operators and contractors must exercise due diligence when selecting elastomers for the well control and fluid circulation system. ASTM D471 provides a standard methodology for testing elastomers to determine the effect a base oil and/or additives and/or temperature will have on a given elastomer component.

Any oil based drilling fluid low in aromatic content (high aniline point) may become contaminated by formation fluids potentially high in aromatics. These components can have a far greater effect on BOP elastomers than the original drilling fluid. When selecting elastomers, therefore, the characteristics of formation fluids that may be encountered in the well must be considered as well as the drilling fluid type. This would also include the potential of encounters with even minimal amounts of H_2S which creates an additional elastomer degradation factor.

Remember, aromatic content is not just a threat to elastomers—aromatic content carries with it exposure risks. The higher the aniline point, the lower the aromatic content. As a general principle, choosing fluids with the highest possible aniline points will carry the double advantage of reducing both operational hazards and exposure related health hazards.

14.3.2.3 Slippery Surfaces

IRP Employers should ensure oily surfaces resulting from the use of non water based drilling fluid are addressed through good ongoing housekeeping practices and that all spills and leaks are addressed quickly.

Most oil base fluids are designed to oil-wet surfaces and will do so if they come in contact with floors, stairs, railings or any other surface. Oily surfaces are a slipping hazard that should be controlled with good housekeeping practices and products that are effective at reducing slipping hazards for specific areas such as the drilling floor.

14.3.2.4 Late Kick Detection

IRP Rigs drilling with non water based drilling fluids shall be equipped with alarms and sensors with sufficient sensitivity to provide drilling crews the earliest meaningful warning of a downhole influx of gas.

IRP In addition to the required standard blowout prevention training, rig crews working with non water based drilling fluids should be

- made aware of the increased risk of late kick detection with these fluid systems and
- competent in the implementation and interpretation of sensors and alarms designed to detect and warn of a downhole influx of gas.

Note: Training material on the recognition of kicks, kick behavior, and preventive controls when using oil based muds (OBM) is provided in the 2014 editions of First Line Supervisor’s Blowout Prevention and the Second Line Supervisor’s Well Control course textbooks.

Hydrocarbon gases are soluble in all oils used for drilling fluids. When a gas influx occurs at the bottom of the well, the gas may largely dissolve into the non water based drilling fluid, especially if the rate of the gas influx is not large compared to the circulating rate of the fluid.

The symptoms of an influx of gas with water based drilling fluids can include an increase in circulation rate, a sudden change in drilling rate, a change in pump pressure, a reduction in drill pipe weight and/or mud weight, and a change in mud texture (it becomes fluffy). With non water based fluids, these symptoms are delayed. The influx of gas may not be immediately apparent at surface. The gas can stay in solution with the oil-based mud until it gets close to surface. At that point the hydrostatic pressure of the drilling fluid drops below the effective bubble point of the solution. The gas then breaks out and can cause a rapid increase in flow rate followed quickly by gas to surface. In a worst case scenario, an unexpected and uncontrolled large scale release of gas and hydrocarbon based fluid takes place at the surface. This creates an immediate threat of fire and explosions as well as the associated exposure hazard for workers on site and those involved in the subsequent clean up.

This operational hazard needs to be addressed with both administrative controls (such as barrier policies and required training) and engineering controls. While gas may dissolve in the non water based fluids, there will still be some measurable increase in the volume of the non water based fluid as it takes on gas. A variety of sensors and alarms for early detection are critical to ensure sufficiently early warning of an impending gas kick. It is especially important that rig crews with exclusive experience using water-based drilling fluid are fully informed of additional hazards presented by the use non water based drilling fluid including late kick detection. These crews need to be provided appropriate training and/or competency assessment in this regard.

14.4 Identifying Key Hazard Areas

14.4.1 Chemical Exposure Scenarios in Drilling Operations

14.4.1.1 Overview

There are a number of work areas and tasks in a typical drilling operation that create the possibility of workers being exposed to non water based fluids either through inhalation or skin contact. Exposure hazards begin in the mixing area, where airborne chemical dust may well present a hazard. Once mixed, exposure hazards exist where the drilling fluid is open to the atmosphere and especially when the fluid is agitated. Airborne mist may be produced directly by the agitation or secondarily as oil vapours condense in the air. Areas of high exposure to airborne vapours and mist are usually easy to identify by workers using smell, sight and feel on the skin. Some typical exposure areas include the following:

- Near shale shakers, centrifuge discharges, or any equipment causing high mud agitation.
- Near fluid discharge lines (e.g., centrifuge return) or mud tank mixers that cause splashing.
- Near a high-pressure wash gun.
- On top of the mud tanks.
- In enclosed areas such as on covered mud tanks, in the substructure, and inside mud tanks when cleaning.

There are also tasks which can result in workers' skin coming in contact with the fluid. The most common include the following:

- Floor hands tripping pipe and making connections.
- Catching samples off the shale shaker.
- Changing shaker screens or repairing pumps or other equipment.
- Pressure washing (note: pressure washing with any base oils or diesel should be prohibited—see Enform document *Review of Diesel Use in Pressure Wash Gun in the Upstream Petroleum Industry*).
- Rigging-out BOPs, tank farms, and solids control/shale handling equipment

If the fluid becomes an airborne mist, there is a potential for fluid contact with all exposed skin.

A number of factors will influence the workers' exposure levels. Drilling fluid temperatures, flow rate, well depth, well section, and the viscosity of the fluid all play a role. Ambient conditions, including temperature and wind direction and speed, will create variables.

As a general rule, higher fluid temperatures lead to high vapour levels as shown Figure 5 illustrating vapour levels for diesel based fluids at 20°C versus those at 80°C. At 70°C some mineral base oils may evaporate at a rate as high as 1% by volume per 10 hour period. As these vapours cool, they condense and now increase the risk of oil mist exposure. Increasing temperatures may also increase the amount of oil mist produced by agitation of the fluid.

Figure 5. The effect of rising temperature on diesel vapour levels

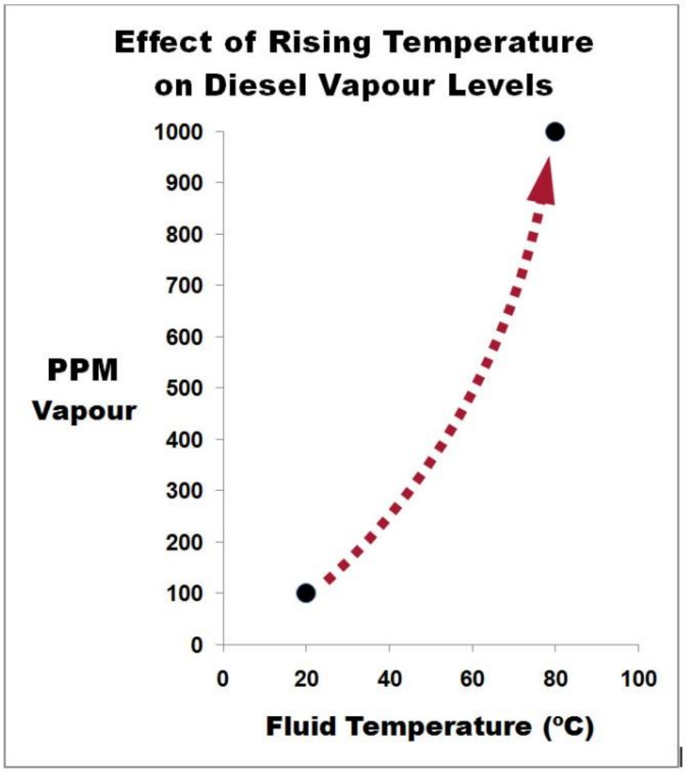
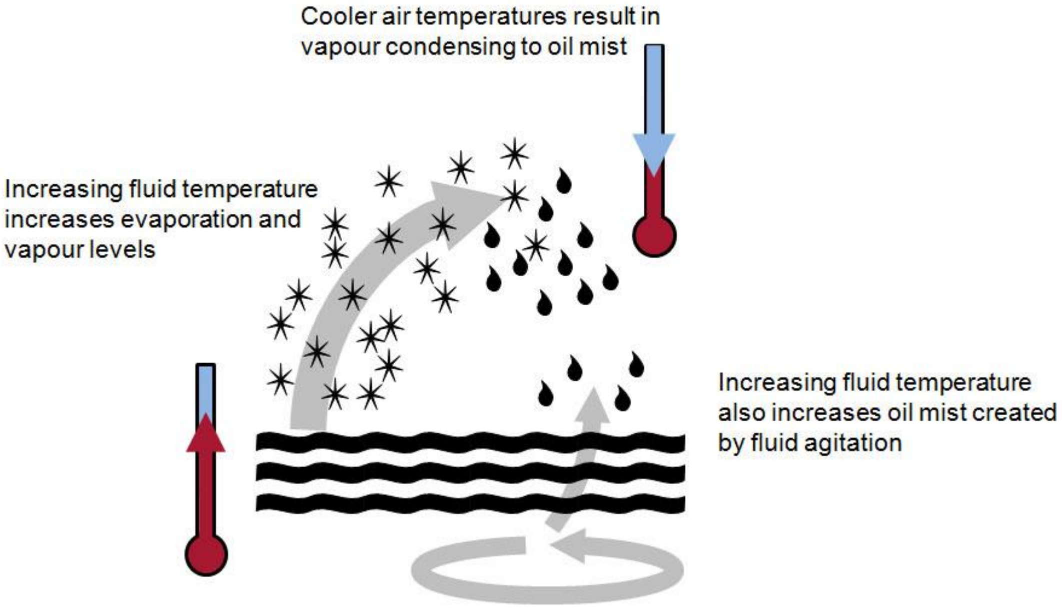


Figure 6. The effect of temperatures on vapour and mist levels



Note that it is not just the oil base creating the vapour. Drilling fluid additives and additional hydrocarbons from the formation affect the makeup of the vapour. This may be especially problematic if these generate higher than expected lighter hydrocarbon components.

There are also variables in dermal exposure. The most important is the duration of exposure. Inappropriate PPE may actually prolong skin contact. For example, fabric gloves soaked in hydrocarbons or impermeable gloves that are contaminated from the inside serve to keep fluid pressed up against the workers' skin, multiplying the exposure risk.

14.4.1.2 Exposure Scenarios

IRP The exposure scenarios detailed in tables 8 through 15 should be consulted as appropriate by those involved in the design, planning, or implementation of drilling programs that will utilize non water based drilling fluid as well as anyone involved in the supervision of workers on oil and gas lease sites where non water based drilling fluid will be stored and used. Frontline workers may also be introduced to these tables as a component in their training in the identification and control of hazards related to non water based drilling fluids.

The following table have been adapted and developed from those provided in *Drilling fluids and health risk management* (IPIECA/OGP: 2009). These tables are not designed to be exhaustive. They do not provide all the relevant information required to develop a comprehensive and effective exposure control plan for a particular drilling operation.

Rather, these tables are designed to provide health and safety specialists better insight into the types of tasks and the nature of tasks on a typical drilling operation that may create an exposure risk for the workers. As such, it is a useful starting point for developing a comprehensive exposure control plan (see Appendix B: Exposure Control Plan [ECP] Template). These tables may also provide workers with insight into where they face exposure risks in their tasks and provide answers as to why specific control measures are essential in particular operational areas or during specific tasks.

In the following tables, the final column offers example controls. As much as possible, the committee tried to offer engineering and administrative controls rather than reinforce reliance on PPE. However, given that correct PPE is critical in many of these activities, the following codes for PPE will be used to simplify the tables.

Table 7. PPE Codes Used in Drilling Scenario Tables

Reference number	Description
Standard	Fire resistant (FR) coveralls, safety glasses, hard hat, steel toed boots, hearing protection, hand protection, barrier cream
1	Standard + nitrile boots + nitrile gloves
2	Standard + 1 + nitrile arm bands
3	Standard + 1+ FR and oil resistant rain suit
4	Standard + half face respirator (P100/OV Cartridge)
5	Standard + respirator + additional eye protection (either Full Face Respirator [P100/OV Cartridge] or Half Face + Goggles)

In the following tables appropriate ventilation is referenced as a possible control in a number of locations. The generally accepted standard on industrial ventilation is the ACGIH volume, *Industrial Ventilation: A Manual of Recommended Practice*, 28th edition (2013) and as amended from time to time.

14.4.1.2.1 Shale Shakers

Shakers and their immediate surrounding area represent one of the more obvious areas for inhalation and dermal exposures to hydrocarbon based drilling fluids. In this scenario the fluid has been circulated downhole, potentially picking up hydrocarbon contaminants as well as increasing in temperature, is exposed to atmosphere, and is highly agitated. This is also the point at which sampling of both the fluid and well bore solids take place. In addition, the equipment itself requires very regular maintenance and cleaning. In most drilling operations, a number of contracting companies will have workers operating in and around the shakers for various tasks in the drilling operation.

Typically there is an increase in exposure levels with:

- Higher fluid temperatures
- Higher flow rates
- Lower fluid viscosity
- Drilling into/through hydrocarbon bearing zones
- Reduced air flow or ventilation around the shaker

Changing ambient temperatures can also affect exposure levels. Whether higher or lower temperatures pose an increased risk depends on the nature of the fluid and its components. From a monitoring standpoint, measuring exposures at both expected high and low ambient temperatures is a worthwhile exercise. Wind speed and direction are also critical factors in exposure levels.

Offshore drilling operations make use of fully enclosed shale shakers with venting systems. These are not generally used in land based operations. There are emerging ventilation systems involving hoods and exhaust systems being explored for shale shakers and other solids control equipment. These have the potential to reduce vapours and capture and/or contain airborne mist. However, creating effective ventilation systems that reduce overall exposure risks (as opposed to simply relocating the risk) requires design expertise and professional monitoring to assess the revised exposure hazards. As noted above, ACGIH provides industrial ventilation standards.

Table 8. Shale Shakers

Activity	Typical task duration / frequency	Type of exposure	Influencing factors	Examples of controls to consider
Sampling				
Measuring fluid weight and funnel viscosity (before and after the shakers)	Routine operation High frequency ~ 15 minutes total over a 12 hour shift	Skin contact with fluid (hands) Inhalation of vapour/mist	Fluid flow-line temperature Fluid characteristics and composition	Inline or remote flowline testing Process sample away from tanks PPE: 1, 2, 4

Activity	Typical task duration / frequency	Type of exposure	Influencing factors	Examples of controls to consider
Cuttings sampling (taken from the shaker) for oil on cuttings or for geological analysis	~15 minute exposure segments up to 6 hours per shift at peak	Splashes of fluid (face/hands/ body) Skin contact with fluid (hands) Inhalation of vapour/mist	ROP and cuttings loading on screens Fluid flow-line temperature Fluid characteristics and composition Equipment design (e.g., open air / enclosed)	Create remote sample processing area away from shakers Use benign solvents for sample washing (e.g., water based fluids with detergents) Use sample washer ("parts washer") PPE: 1,3,4
Maintenance				
Changing shaker screens and other routine maintenance	Intermittent routine operation; Up to 30 minutes per 12 hour shift	Inhalation due to general work environment Skin contact with fluid contaminated surfaces	ROP Shaker design (e.g., open air / enclosed) Ergonomics Screen durability	Perform operations when pumps are off or at the end of operations if possible Ensure air movement (e.g., fully open to atmosphere) or appropriate ventilation PPE: 1,3,4
Modification or repair of shakers	As required	Inhalation due to general work environment Skin contact with fluid contaminated surfaces	Shaker design and reliability Ergonomics	Perform operations when pumps are off or at the end of operations if possible Ensure air movement (e.g., fully open to atmosphere) or appropriate ventilation Clean shaker prior to repair PPE: 1, (if mud in tanks) 3,4

Activity	Typical task duration / frequency	Type of exposure	Influencing factors	Examples of controls to consider
Cleaning operations: • screens • general workplace • header box / possum belly	As required	Inhalation due to general work environment and mist/aerosol from cleaning methods/ materials Skin contact with fluid contaminated surfaces Splashes to face/body/hands	Cleaning methods/ equipment/ agents Ergonomics	Ensure air movement (e.g., fully open to atmosphere) or appropriate ventilation Perform operations when pumps are off if possible Use brushes or steam vs. pressure washers when appropriate PPE: 1,3,4
Inspection / Monitoring				
Inspecting gas trap / header box	Routine operation High frequency ~ 15 minutes total over a 12 hour shift	Inhalation due to general work environment Splashes to hands	ROP Ergonomics Design and layout of equipment	Ensure air movement (e.g., fully open to atmosphere) or appropriate ventilation Perform operations when pumps are off if possible PPE: 1,2,4
Monitoring shaker operation or screens, e.g., monitoring for screen blinding or damage to screen mesh	Routine operation High frequency >5 minutes/hour	Inhalation due to general work environment Splashes to face/body/hands	Ergonomics Design and layout of equipment Solids characteristics/ volume Screen selection	Ensure air movement (e.g., fully open to atmosphere) or appropriate ventilation Remote shaker viewing by video camera PPE: 1,4

14.4.1.2.2 Other Solids Control Equipment/Tasks

In addition to shale shakers, drilling operations may include other equipment and tasks related to solids control that must be considered when evaluating exposure risks. These include:

- Centrifuge
- Desilters
- Desanders
- Fluid Transfer Pumps

- Shale Handling Equipment
- Mixing Off / Loading Cuttings

To a large extent, what applies to shale shakers applies equally to other well bore solids handling equipment. Generally there are increased exposure levels in and around solids control equipment whenever the following occur:

- Higher fluid temperatures
- Higher flow rates
- Lower fluid viscosity
- Drilling into/through hydrocarbon bearing zones
- Reduced air flow or ventilation around the equipment

Table 9. Other Solids Control Equipment/Tasks

Activity	Typical task duration / frequency	Type of exposure	Influencing factors	Examples of controls to consider
Monitoring				
Monitoring ancillary solids control equipment during operations	Routine operation High frequency >5 minutes / hour	Inhalation due to general work environment Splashes to face, body, hands	Ergonomics Design and layout of equipment Solids characteristics and volume	Electronic monitoring where possible Ensure air movement (e.g., fully open to atmosphere) or appropriate ventilation PPE: 1,4
Sampling				
Cuttings sampling taken from the ancillary solids control equipment (e.g., centrifuge)	Varies with operation Maximum ~10-15 minute segments to a total of 3 hours over a 12 hour shift	Splashes of fluid (face/hands/ body) Skin contact with fluid (hands) Inhalation of vapour/mist	ROP and cuttings loading on screens Fluid flow-line temperature Fluid characteristics and composition Equipment design (e.g., open air vs. enclosed	Create remote sample processing area away from shakers Use benign solvents for sample washing (e.g., water based fluids with detergents) Use sample washer ("parts washer") PPE: 1,3,4

Activity	Typical task duration / frequency	Type of exposure	Influencing factors	Examples of controls to consider
Inspection / Maintenance / Repair				
Inspection, maintenance or repair of ancillary solids control equipment	Varies with operation and equipment type	Inhalation due to general work environment Skin contact with fluid contaminated surfaces Splashes to face/body/hands	Ergonomics Design and layout of equipment	Perform operations when pumps are off or at the end of operations if possible Ensure air movement (e.g., fully open to atmosphere) or appropriate ventilation PPE: 1 and, as appropriate 2, 3, or 4
Tear Down				
Tear down of solids control and fluid handling systems at end of drilling operations	Once per well	Inhalation due to general work environment Skin contact with fluid contaminated surfaces Environmental release	Fluid composition at end of operations Equipment design Weather conditions Surface water	Ensure cleaning of equipment for next rig up prior to move Use brushes or steam vs. pressure washers when appropriate PPE: 1,3,4

14.4.1.2.3 Mixing Hopper / Adding Solids and Liquids to Fluid

Over the course of a drilling operation, the drilling fluid is regularly adjusted to meet the changing requirements of the drilling operation. Both solids and liquids are added to the drilling fluid as operations proceed. This frequently takes place in an enclosed or semi-enclosed area with a mixing hopper. Solids and liquids are poured into the wide top of the hopper while the narrow bottom section of the cone-shaped hopper has a fluid circulating pipe passing through it, drawing the materials being added into the circulating fluid. This work is typically manual, with workers opening bags of powders or pellets and physically pouring these in one at a time. Liquids may be poured in from cans or transferred from barrels.

This mixing area presents both an inhalation hazard from dust when solids are added (a problem common to both water and non water based fluid systems) and skin contact hazards from splashing liquids. Powdered materials may also present a skin contact exposure hazard. Natural or artificial ventilation of this mixing area will affect the exposure risk as will the general layout of the workspace in the shack. Once sacks or other containers are emptied, exposure hazards for disposing of these items need to be considered.

Mixing solids and liquids into the fluid is not isolated to the mixing shack/hopper. Both solids and liquids may be added directly to the mud tanks/"pits" apart from the hopper. Exposure hazards may be reduced by managing the location and defining the appropriate methods for adding solids and liquids directly the tank.

Table 10. Mixing Hopper

Activity	Typical task duration / frequency	Type of exposure	Influencing factors	Examples of controls to consider
Adding Solids to Drilling Fluid				
Mixing through a venturi hopper	Variable, up to 12 hours on a given shift	Drilling fluid system additives: inhalation of dust and skin contact Skin contact with contaminated surfaces	Venturi hopper design Packaging type Bulk transfer tanks Solid material characteristics Volume to be mixed Wind direction in an open environment	Local Exhaust Ventilation (LEV) Dilution ventilation PPE: 3, 4
Direct mixing into tank/mud tank	Variable, up to 12 hours on a given shift	Drilling fluid system additives: inhalation and skin contact of dust Skin contact with contaminated surfaces Splashes to face/body/hands	Mix system configuration Packaging type Solid material characteristics Volume to be mixed	Create and adhere to a fixed location for chemical mixing PPE: 4

Activity	Typical task duration / frequency	Type of exposure	Influencing factors	Examples of controls to consider
Adding Liquids to Drilling Fluid				
Adding liquid directly to mix tank/ mud tank	Variable, up to multiple hours on a given shift	Drilling fluid system additives: skin contact with contaminated surfaces and inhalation of vapours Splashes to face/body/hands	Mix system configuration Packaging type Liquid material characteristics Volume to be mixed	Create and adhere to a fixed location for chemical mixing PPE: 3,5
Adding Highly Caustic and Corrosive Chemicals				
Mixing through an approved chemical barrel or tank (only recommended method)	Variable, minutes to hours	Skin contact with contaminated surfaces Splashes to face/body/hands Inhalation of vapours	Barrel placement Type of agitation Volume to be mixed Corrosiveness of chemical to be mixed Temperature of water being mixed Order of addition	Written safe work procedure Ensure procedure outlines correct mix order (i.e., add chemicals to water, not vice versa) PPE: 3,5 ***Caution: Barrier creams can react with caustic beads causing severe burns due to the water content of the cream**
Handling Packaging				
Handling and containment of waste packaging materials, sacks, big bags, drums, intermediate bulk containers	Variable, up to multiple hours on a given shift	Drilling fluid system additives: skin contact with contaminated surface Dust and vapour inhalation from handling waste	Packaging type Chemical characteristics Chemical compatibility Waste collection, storage and disposal methods	Written safe work procedures (as per product MSDS) Define containment and disposal areas PPE: 4 (solids packaging); 5 (liquids containers)

14.4.1.2.4 Drilling Fluid Tanks

Any personnel working around but especially over top of open drilling fluid tanks, may be exposed both to hydrocarbon vapours and oil mist. There is potential for both inhalation and skin contact hazards. Equipment installation, maintenance, and direct-to-tank mixing (as per above) are work activities that may be carried out above open tanks.

Depending on the layout of the drilling operation, workers may also be required to traverse over top of the drilling fluid tanks for a variety of tasks.

The exposure risk is influenced by a number of factors. As noted above with solids control equipment, the following tend to increase the risk of vapour and oil mist exposure:

- Higher fluid temperatures
- Higher flow rates
- Lower fluid viscosity
- Drilling into/through hydrocarbon bearing zones
- Reduced air flow or ventilation around the equipment
- Lower ambient temperatures

Table 11. Drilling Fluid Tanks

Activity	Typical task duration / frequency	Type of exposure	Influencing factors	Examples of controls to consider
Working in vicinity of tanks				
Working on equipment adjacent to or above tanks; traversing above open tanks	Variable, intermittent, minutes to hours	Inhalation of vapour/mist	Temperature of fluid Fluid surface area exposed Fluid agitation Workplace design	Time work to mitigate exposure Hazard signage around tanks PPE: 4
Tank cleaning				
Removal of fluids/solids and cleaning of tank interior surfaces	Up to 6 hours once or twice per well	Splashes, contact with contaminated surfaces, inhalation of vapour/mist	Temperature Ergonomics tank design Confined spaces Cleaning equipment design and operating methods Lighting	Use low shear tools such as brush and squeegee rather than wash guns. Low shear wash guns will reduce vaporization risk Safe Work Agreement *Continuous atmospheric monitoring and venting is required for confined space entry PPE: 5 (give additional consideration to respirator cartridge lifespan)

Activity	Typical task duration / frequency	Type of exposure	Influencing factors	Examples of controls to consider
Fluid Transfers				
Movement of bulk fluids between tanks, possibly using flexible hoses and pumps Circulation of fluid within tank	Limited to connection and transfer time	Contact with contaminated surfaces Inhalation of vapour/mist. Potential for splashing	Transfer and agitation equipment design Pressure Operating methods Tank and tank farm design Ergonomics	Appropriate monitoring and JSA / Safe Work Procedure Consider hammer unions vs. cam lock system Install drip trays at joints PPE: 1

14.4.1.2.5 Chemical/Fluid Storage and Handling

The management of chemicals on the lease site should begin with its initial arrival and storage on the worksite. Base fluids are typically brought in via tanker truck and pumped into onsite storage tanks. Solid and liquid additives may arrive in bulk and/or in sacks, cans, and barrels (frequently packaged on pallets). Exposure hazards may be created through improper bulk transfer procedures or may arise if manual handling of products is required. Outdoor storage of many of these products is common, which tends to minimize inhalation hazards during storage. However, whenever indoor storage takes place, exposure hazards may be created if packaging or containers fail.

Table 12. Exposure Control – Chemical/Fluid Storage and Handling

Activity	Typical task duration / frequency	Type of exposure	Influencing factors	Examples of controls to consider
Sack and drum storage of chemical additives to be used in mixing process	Intermittent, short term (minutes)	Skin contact with contaminated surfaces Dust and vapour inhalation from handling damaged packaged materials	Packaging type Chemical characteristics Layout and design of storage area (enclosed vs. open air storage) Volume stored	Indoor storage may require ventilation to reduce silica dust and harmful vapor concentrations. Ensure effective lighting, stair railings and slippery surfaces. Install appropriate signage re: inventory, access, and controls PPE: If packaging or containers compromised, 1, 3, or 4 as appropriate
Manual handling of sacks and drums of chemical additives to and from mix area	Variable, intermittent (minutes to 12 hours per shift)	Skin contact with contaminated surfaces Dust and vapour inhalation from handling damaged packaged materials	Packaging type Chemical characteristics Ergonomics	Consider use of bulk products when possible (e.g., barite) PPE: 1 (solids); 3 (liquids)
Mechanical handling of packaged chemical additives to and from mix area	Variable, intermittent (minutes to 12 hours per shift)	Dust and vapour inhalation from handling damaged packaged materials	Packaging type Chemical characteristics	To reduce potential spills, ensure pallets are shrink wrapped while being moved. PPE: Consider 1 and 4 if packaging / containers are damaged

Activity	Typical task duration / frequency	Type of exposure	Influencing factors	Examples of controls to consider
Unloading tankers on lease site into storage areas (tank farm or active system)	Limited to connection and transfer time	Skin contact with contaminated surfaces Vapour inhalation	System design Fluid temperature Ambient temperature	Consider the following engineering controls: · internal manifold filling pressure system · double walled tanks · secondary containment of tank and transfer area · Inject liquids into bottom of tanks to reduce splatter and atomization of transferred liquid · use hammer unions rather than cam locks to reduce leaks · Install drip trays at joints Appropriate monitoring and JSA / Safe Work Procedure PPE: 3

14.4.1.2.6 Rig Floor

The rig floor presents both skin and inhalation exposure hazards that are frequently continuous over the course of a full twelve hour shift. The extensive manual handling of equipment that may be coated in drilling fluid (in addition to contact with lubricants, pipe dope, hydraulic oils, etc.) makes skin exposure a constant primary concern in this area. Inhalation exposure hazards will depend on the nature of the fluid, fluid temperature, ambient temperature, etc., as already discussed. The general ventilation of the rig floor area is also a factor. The difference between summer and winter drilling operations play a role here. Tarps are often used to shelters workers from the cold but these may also trap vapours and mist and affect exposure levels.

Housekeeping on the rig floor should also be considered. Unclean surfaces from spills or mist as well as cleaning processes such as pressure washing need to be considered when evaluating rig floor exposures.

Table 13. Rig Floor

Activity	Typical task duration / frequency	Type of exposure	Influencing factors	Examples of controls to consider
Make up of drill string during drilling operations	Intermittent to continuous during active drilling operations (up to 12 hours per shift)	Skin contact with contaminated surfaces, clothing or pipe dope Splashes Inhalation and skin contact from vapour/mist Ingestion from contaminated hands.	Characteristics of pipe dope Degree of automation of drill floor activities Fluid temperature Ambient air temperature	Consider equipment automation / design to keep workers away from or minimize time in high exposure areas: · Power slips · Make & break units · Top drive · Hydraulic catwalk & pipe arm Maximize containment systems: · Kelly strippers · Pipe strippers · Mud cans · Mud saver valve · Rotary table splash barrier PPE: 1 (dry connections); 3 (wet connections); consider 4 if enclosed structure / poor ventilation / poor air quality as determined by ECP
Tripping in/out of hole for cleaning and conditioning the well bore in preparation for casing & cement or treating hold problems related to poor cleaning / circulation	Continuous during tripping operations (up to 12 hour shift)	Skin contact with contaminated surfaces, clothing or pipe dope Splashes Inhalation and skin contact from vapour/mist Ingestion from contaminated hands.	Trip in vs. trip out Characteristics of pipe dope Degree of automation of drill floor activities Fluid temperature Ambient air temperature Degree of ventilation	Pump weighted pills prior to tripping out of the hole whenever possible. (see above – drilling operations) PPE: 1 (dry trip in); 3 (wet trip out); consider 4 if enclosed structure / poor ventilation / poor air quality as determined by ECP

Activity	Typical task duration / frequency	Type of exposure	Influencing factors	Examples of controls to consider
Run Casing	Continuous during casing operations (as short as an hour, up to 12 hours per shift)	Inhalation and skin contact from vapour/mist	Degree of automation of drill floor activities Fluid temperature Ambient air temperature	Focus on rig system automation to reduce worker exposure. PPE: Standard
Fishing (retrieving tools stuck in the wellbore by use of wash over pipe and mechanical back-off of drill string)	Rare, disruption activity (typically multiple hours)	Skin contact with contaminated surfaces, clothing or pipe dope Splashes Inhalation and skin contact from vapour/mist Ingestion from contaminated hands.	Characteristics of pipe dope Degree of automation of drill floor activities Fluid temperature Ambient air temperature	Ad hoc JSA development / hazard assessment Very specific administrative controls to keep workers away from cascading drilling fluid. Supervisory vigilance to protect workers from working in invert soaked clothes PPE: 1 (dry trip in); 3 (wet trip out); consider 4 if enclosed structure / poor ventilation / poor air quality as determined by ECP
Well Testing (isolation of the target formation and recording wellbore pressure and composition information)	Frequent in exploration drilling programs (up to 6 hours per shift of handling tools) Carried out in conjunction with continuous tripping in and out of the well bore.	Skin contact with contaminated surfaces, clothing or pipe dope Splashes Inhalation and skin contact from vapour/mist Ingestion from contaminated hands.	Characteristics of pipe dope Degree of automation of drill floor activities Fluid temperature Ambient air temperature	PPE: 1 (dry trip in); 3 (wet trip out); up to 5 or even SCBA depending on formation fluid being recovered

Activity	Typical task duration / frequency	Type of exposure	Influencing factors	Examples of controls to consider
Retrieving geological core samples from a target formation	Up to 2 hours of core processing on the rig floor for each core that is cut. Carried out in conjunction with continuous tripping in and out of the well bore.	Skin contact with contaminated surfaces, clothing or pipe dope Splashes Inhalation and skin contact from vapour/mist Ingestion from contaminated hands.	Fluid characteristics Characteristics of pipe dope Degree of automation of drill floor activities Fluid temperature Ambient air temperature	Use wire line retrievable coring techniques to reduce exposure to workers. PPE: 1 (dry trip in); 3 (wet trip out); consider 4 if enclosed structure / poor ventilation / poor air quality as determined by ECP; up to 5 or even SCBA depending on formation fluid being recovered
Inspection and maintenance of rig floor equipment	Up to 1 hour per shift	Skin contact with contaminated surfaces, clothing or pipe dope Splashes Inhalation and skin contact from vapour/mist	Design of drilling equipment Maintenance frequency Ambient air temperature	PPE: Standard
Removal of fluid contamination in and around rig floor	During operations, intermittent. Up to 2 hours per day on the rig floor alone	Splashes, skin contact with contaminated surfaces Inhalation of vapour/mist aerosol	Type of cleaning equipment and agents used Design of drill floor	PPE: 3 or 5 depending on equipment used (e.g., spray gun) and contaminants

14.4.1.2.7 Fluid Testing / Lab / Geologist Work Area

Both drilling fluid engineers (the “mud man”) and geologists need to work with the drilling fluid in their respective roles. Once drilling operations are underway, both may be involved in multiple tests per day. Their work areas may vary, but in some case they will have a dedicated “lab space” or structure where they can conduct their testing procedures. In addition to potential contact with the non water based drilling fluid, tests themselves may require handling other hazardous chemicals. Equipment to dry samples or heat samples to boil off the fluid fractions can create gases. Fume hoods and ventilation may be required. However configured, the fluid testing and geologist work areas should always be separate from any eating or sleeping areas.

Table 14. Fluid Testing / Lab / Geologist Work Area

Activity	Typical task duration / frequency	Type of exposure	Influencing factors	Examples of controls to consider
Sample washing to evaluate geological formation	Up to 12 hours per shift during active drilling operations	Skin contact eye contact Inhalation	Temperature of sample wash Ventilation	Stainless steel wash area Enclosed hot fume hood (Class 1 Div 1) PPE: 1
Drying sample with vacuum to evaluate geological formation	Up to 12 hours per shift during active drilling operations	Inhalation Skin contact	Composition of organic solvents Venting method Sample rate	Dedicated sample washing area Enclosed hot fume hood (Class 1 Div 1) PPE: 1
Dry sample checking; includes use of trichloroethylene or hydrochloric acid solution	~5-20 minutes per shift	Inhalation Skin contact Eye contact	Proximity to the product Venting method Sample rate	Ensure adequate ventilation PPE: 1,4
Mud testing to determine physical properties (density / viscosity)	~10-15 minutes per test; up to 1 hour per shift	Inhalation Skin contact Eye contact	Testing may take place above mud tanks or lab testing area Mud temperature and viscosity Testing area ventilation / venting method	Ensure adequate ventilation PPE: 1,4
Mud testing to determine mechanical properties (by fluid engineer/ "mud man": Retort, HTHP; Rheology; Electrical Stability; OOC; AW testing	Up to 2 hours per test; up to 4 hours per shift	Inhalation Skin contact Eye contact	Testing area ventilation Testing area space Extreme equipment temperatures and pressures	Enforce administrative controls on testing area housekeeping and safety Ensure adequate ventilation Provide readily accessible eye wash station Have testing equipment cooling area PPE: 1,4

Activity	Typical task duration / frequency	Type of exposure	Influencing factors	Examples of controls to consider
Mud testing to determine chemical analysis (by fluid engineer / "mud man")	Up to 1 hr/test; up to 2 hrs/shift	Inhalation Skin contact Eye contact	Testing area ventilation Testing area space	Enforce administrative controls on testing area housekeeping and safety Ensure adequate ventilation Provide readily accessible eye wash station PPE: 1,4
Disposal of waste liquid chemicals and solids after testing	Duration of combined tests	Inhalation Skin contact Eye contact	Disposal and containment practices	Enforce administrative controls on containment and disposal procedures (e.g., labeled containers) PPE: 1

14.4.1.2.8 Cuttings Handling

Table 15. Cuttings Handling

Activity	Typical task duration / frequency	Type of exposure	Influencing factors	Examples of controls to consider
Conveying cuttings from shaker or other solids handling equipment to cuttings mix-off and containment in preparation for transport	During operations, intermittent	Skin contact from splashes or contaminated equipment surfaces Inhalation and skin contact from vapour	Wind direction Mix off materials and methods	Minimize movement on lease with close proximity between rig and mix-off facilities Matting in operating area to minimize spills and splashing PPE: 1
Loading and transport of cuttings off lease	During operations, intermittent	Skin contact from splashes or contaminated equipment surfaces Inhalation and skin contact from vapour	Effectiveness of binding material Containment system design Loading methods	Cuttings bin sealed when loaded and moved. Paint filter test to determine free oil content and effectiveness of binding materials PPE: 1

14.4.2 Safety Hazards Presented by Non Water Based Drilling Fluids

14.4.2.1 Overview

IRP Personnel involved in the implementation and supervision of drilling operations using non water based drilling fluid shall eliminate and/or mitigate the risk of fire and explosion as much as is reasonably practicable. This includes the elimination and/or control of any ignition sources in the vicinity of the drilling fluid.

IRP Controls that shall be standard practice on any drill site utilizing non water based drilling fluid include, but are not limited to, the following:

- **All electrical equipment in the vicinity of the fluid circulation system or fluid transfer areas must be in compliance with provincial codes for electrical installations at oil and gas facilities (e.g., Class 1, Division 2 minimum).**
- **All diesel engine vehicles and equipment working within 25 metres of non water based fluids must have engine air intake shutoffs installed.**
- **Designated smoking areas if permitted shall be located a minimum of 25 metres from any locations where non water based fluids are circulated, stored or transferred.**
- **Appropriate cleaning products shall be made available and housekeeping administrative controls shall be enforced to manage slippery surfaces (including floors, stairs, and railing) that arise from the use of non water based drilling fluid.**

In the scenarios presented in 14.4.1 Chemical Exposure Scenarios in Drilling Operations, the concern was mitigation of exposure risks. In addition to these concerns, drilling operations using non water based drilling fluids also need to consider the fire and explosion hazard created by the potential flammability or combustibility of non water based drilling fluids or components of that fluid.

Mitigating the risk of fire and explosion hazards related to non water based drilling fluids requires a knowledge and ongoing monitoring of the fluid itself, including:

- On site information on the base oil and other drilling fluid components
- Any history of the drilling fluid before its arrival on site (e.g., if it is recycled whole mud from another drilling operation and, as such, potentially contaminated by formation fluids, additives not properly tracked, or accidental mixture with other fluids in storage or transport)
- The oil/water ratio
- The fluid flashpoint (see 14.5.1.1 Flash Point).

Note: Based on the history of a whole mud and over the course of the operation, the flashpoint provided on the MSDS for a given base oil or other fluid additives may not accurately reflect the flashpoint of the fluid as it actually exists on site.

Mitigation of the risk of fire and explosion hazards also requires elimination and/or control of ignition sources when drilling with non water based fluids. Potential ignition sources during drilling operations include, but are not limited to, the following:

- Sparks from electrical equipment or tools
- Sparks, arcs, and hot metal from welding, cutting, or grinding
- Smoking
- Open flames from propane torches, engine pre-heaters, and boilers
- Hot surfaces such as engine exhaust, boilers, electric coils, and hot bearings
- Embers and sparks from incinerators and engine exhaust
- Sparks caused by static electricity from improper transfer of liquids
- Sparks caused by static electricity from oil based mud products sliding on plastic shale handling equipment

14.4.2.2 Risk Factors and Controls by Work Areas and Tasks

IRP Table 16 outlining risk factors by work areas and tasks should be consulted as appropriate when performing hazard identification and risk assessments and developing hazard controls for non water based drilling operations.

In addition to these general recommendations, a table has been provided that highlights risk factors and sample controls for work areas and tasks affected by non water based drilling fluids. As with the exposure scenario tables, these are not designed to be exhaustive. They do not provide all the relevant information required to develop a comprehensive and effective hazard control plan for a particular drilling operation. Rather, these tables are designed to provide those performing hazard identification and risk assessments and developing controls insight into the types of equipment and tasks where drilling fluid is present. As such, it is a useful starting point for developing a more comprehensive system of hazard controls. These tables may also provide workers with insight into where fire and explosion hazards may present themselves.

Table 16. Risk Factors and Controls by Work Areas and Tasks

Work Areas	Tasks	Risk Factors	Examples of Controls to Consider
Tank Farm	Loading, unloading and transfer of hydrocarbon based fluids	Vehicle exhaust Static discharge from vehicle	Position vehicle to maximize distance between flammable fluids and exhaust. Bond transfer lines. Grounding lines to tanks and vehicles Positive air shutoff on truck engine Use straps on cam locks Regular inspection of hoses and manifold and any other transfer equipment; Combustible gas detection system
	Storage of fluids	Static discharge Spill potential Substandard containment Electrical failure	Use hammer unions whenever possible to minimize spill potential Ground cables on tanks Positive air shut off on generator engines Use of ball valves for rapid shutoff or isolation Proper venting on tanks Adequate fire suppression system available for tank farm
Mud Tanks	Circulation of fluid	Electrical failure in agitators or lights Ventilation Shaker damage Leakage in transfer lines	Regular and robust inspection and maintenance schedule and procedures, and immediate repair of all electrical system components around tanks Proper protection of fluid lines and electrical lines between tank farm and mud tanks
	Maintenance and cleaning	Residual flammable fluid Combustible vapours Vaporization during use of wash guns Static from vac truck operations	Inspection and maintenance of clean out gates to ensure seal Bonding cable between vac truck and tank Administrative controls on tank entry (i.e., confined space entry requirements)

Work Areas	Tasks	Risk Factors	Examples of Controls to Consider
Mixing Hopper	Adding solids to fluids	Splash Electrical failure Vaporization of flammable dust	Regular and robust inspection and maintenance schedule and procedures, and immediate repair of all electrical system components around hopper Dust extraction system Splash containment
Pump House	Pumping fluid	On intake—suction blockage generating release Pump—pressurization generating pop valve failure or ruptured piston creating release Release of hot, pressurized fluid, and possible vapours Diesel engine, electrical components, and static within pump house are potential ignition source	Ensure secondary containment (e.g., hinged plate covers or covers with lexan glass inserts to ensure any drilling fluid from ruptured pistons remains contained within the piston rod cavity) Administrative controls to ensure covers are kept closed during all pumping operations; limiting ignition sources (e.g., curtaining engine or exhaust blankets or wraps to protect turbochargers and exhausts on the engine from being sprayed with drilling fluid) Inspection and maintenance of all electrical components Risk assessment of potential release and fluid contact with electrical/heat sources in pump house
	Maintenance of mud pump (changing liners, valves, etc.)	Release of hot, pressurized fluid, possible vapour	Risk assessment of potential release and fluid contact with electrical/heat sources before task Identify and manage any ignition sources in advance of tasks
Rig Floor	Making connections	Spillage and accumulation of fluid Release of entrained gas / release of gas to surface Ignition sources include sparks from metal on metal contact during connections, electric heaters and components, and testing of downhole tools	Fluid containment equipment in place and properly utilized Administrative controls to ensure good housekeeping Adequate ventilation

Work Areas	Tasks	Risk Factors	Examples of Controls to Consider
Cellar	General activities	Accumulation of fluid from rig floor above Possible ignitions sources include electric heaters and components	Utilize adequate containment system (e.g., mud cans, drip trays, etc.) Inspection and maintenance of all electrical components
	Welding	Accumulation of fluid from rig floor above Sparks from welding operations	Administrative controls (e.g., welding procedures, hot work permit)
Shale shaker and other solids control equipment	Removal of solids from fluid during circulation	Release of entrained gas in fluid Ignitions sources include overheated bearings and electric failures	Regular and robust inspection and maintenance of electric motors; immediate replacement/repair if an issues arise with motors Installation of a mud gas detector at the shale shaker to monitor wellbore returns for any gas that may be encountered
Centrifuge	Removal of solids from fluid during circulation	Spills from connection leaks Ignition source here includes buildup of static electricity and heated drive belts	Run bonding wire from centrifuge and through overflow line, to mud tanks Inspection and maintenance on connections
Areas that utilize steam or electric heaters	Provide heat for crew and operations during winter	Contact between fluid and heater coil	Protect heaters from over-spray of flammable fluids Good housekeeping including keeping all oily rags away from heaters
Change shack	Removal and storage of clothing and boots	Residual fluid on clothing and boots Ignition sources include heaters	Maintain safe distance between heat sources and stored clothing and boots by design and administrative controls

14.5 Monitoring Methods to Determine Risks

14.5.1 Fluid Testing

IRP **Prior to starting any drilling operation with non water based fluid, the fluids to be used shall be evaluated based on closed cup flash point, aniline point, and a gas chromatographic analysis of hydrocarbons components up to C30 (commonly known as GC C30+). This information shall be known for the base oil to be used and for any whole drilling fluid being transferred from a previous job or another owner.**

IRP **In the event the composition of the drilling fluid is altered with fluids not specified in the original program, fluid testing shall be repeated.**

The introduction of formation fluids or accidental mixing with other fluids during storage and transfer may contaminate the original fluid and alter its properties. It is important to recognize that all hydrocarbons will be miscible in any type of oil base drilling fluid. Small amounts of more volatile fluids such as condensates, crudes or fracturing oils with light end components left in tank trucks or storage tanks can significantly alter the fluid’s flash point. It is critical that any used fluids are properly characterized prior to use on another well.

This is equally applicable in those cases where fluids such as condensates, crudes, or other blended hydrocarbon bases are added in the course of the program to adjust mud properties. It is critical that the new flash point is established to determine appropriate controls prior to continuing operations.

14.5.1.1 Flash Point

IRP **The Closed Cup Flash Point, as per Pensky-Martens Closed Cup Method ASTM D-93, shall be used to determine the flash point.**

As noted in 14.3.2.1 Flammability/Combustibility, the flash point of non water based drilling fluid in an open system should be at least 10ºC higher than either the maximum anticipated flow line temperature of the drilling fluid or the maximum anticipated ambient temperature, whichever is the greater, throughout the drilling of the well. It is imperative that the flash point of the fluid in conventional systems always remains higher than the flow line or ambient temperature. Furthermore, a fluid with a Closed Cup Flash Point below 61ºC shall only be used with a fully enclosed circulation system and not in conventional drilling operations.

The Closed Cup Flash Point (CCFP) is a measure of the lowest temperature at which the fluid will flash and ignite when an ignition source is applied near the surface. The higher the flash point, the lower the risk of accidental ignition of the fluid. The CCFP temperature is primarily a function of the light end components. For this reason the CCFP temperature will increase as light ends evaporate off (aging). On the other hand, the CCFP temperature can decrease sharply if the fluid is contaminated by even by a relatively small amount of liquid with light end components.

14.5.1.2 Aniline Point

IRP The aniline point shall be determined using the ASTM D611 test method.

The aniline point is defined as the lowest temperature at which aniline (an aromatic amine/benzene derivative) remains miscible in a specified quantity of an oil product as determined by test method ASTM D611.

Oils high in aromatic content exhibit the lowest aniline point values and paraffin oils the highest. Aniline point therefore provides an indication of the aromatic content of the oil. Generally, for mixed hydrocarbon oils, the lower the aniline point of the oil, the higher its aromatic content.

The aniline point is important for two reasons. First, non water based fluids with higher aromatic content (lower aniline point) usually cause more severe degradation of elastomer components than fluids with lower aromatic content. Fluids with an aniline point above 65°C do not generally cause significant deterioration of rubber components (see 14.3.2.2 Elastomer Degradation in Well Control Equipment). Second, aromatic components are also a major source of adverse health effects. As a result, fluids with higher aniline points (and hence lower aromatic content) are generally preferred.

14.5.1.3 Chemical Analysis

IRP The mass fraction of benzene in the drilling fluid shall not exceed 0.01%.

IRP Toluene, ethyl benzene and total xylenes should each be less than 0.1% mass fraction, and trimethyl benzene should not exceed 0.30%.

The key light-end chemicals in hydrocarbon base oils that may become airborne and present health hazards are the BTEX group and trimethyl benzene. These and other components can be measured by a GC C30+ analysis, ASTM D2887m/5307m.

The GC C30+ analysis can also provide a good indication of overall volatility by examining the total amount of light HC. For example, fluids with a total mass fraction below C10 of less than 1.0% and with less than 0.02% below C7 can generally be correlated to acceptable flash point values.

It is important to note that individual compounds above the C10 range cannot be specifically identified with this analysis. This includes the polyaromatic hydrocarbons (PAHs), some of which have adverse health effects. Naphthalene, the lightest PAH, has a specified regulatory occupational exposure limit. Heavier PAHs including benzo-anthracene, chrysene, and benzo-b-floranthene are suspected carcinogens while benzo-a-pyrene has been classified as a human carcinogen by IARC (notation “1”). Measurement of these components requires mass spectroscopy analysis such as EPA 3545, 8270, and 3611B. Analysis of common base oils samples carried out for IRP 14 (2005) indicated only minor amounts of these compounds. The maximum amount of any of the identified carcinogens in these base oils was 0.0023% mass and most fell well below that amount. No analysis was done to look for heavy metals in the base oils as this was not considered to be a concern in the new fluid products. However, this should be considered in the case of recycled lubricating oil or fuel oils that may contain metals based performance additives.

Table 17. Test Protocols and Recommendations Based on Results

	Test Protocol	Recommendations Based on Results
Flash Point	Pensky-Martens Closed Cup Method ASTM D-93	<61°C – shall not be used in conventional drilling operations -- Fluid Flash Point shall be higher than: • maximum anticipated flow line temperature of the fluid • maximum anticipated ambient temperature *(A safety factor of 10°C should be added)*
Aniline Point	ASTM D611	<65°C – should review all elastomers in the circulation and containment systems to ensure they are sufficiently resistant to degradation from aromatics
Chemical Analysis (Gas Chromatography)	GC C30+ Analysis, ASTM D2887m / 5307m	Benzene – shall not exceed 0.01% mass fraction -- Toluene, Ethyl Benzene, total Xylenes – should not exceed 0.1% mass fraction -- Trimethyl Benzene – should not exceed 0.30% mass fraction

14.5.2 Exposure Monitoring

IRP As a general rule, occupational monitoring of airborne chemical exposure levels should be conducted whenever fluid properties or operating conditions exist that may result in over-exposure of workers. This testing should be done in accordance with established methods (e.g., NIOSH, *Oil Mist Monitoring Protocol* [CAPP Guide, December 2004]).

IRP Whenever exposure levels exceeding 50% of the specified OEL/TLV limits are detected, steps shall be taken to reduce the exposure levels or provide the necessary PPE. In British Columbia, employers must develop and implement an exposure control plan once this threshold is reached or if measurement of 50% of the specified exposure limit is not possible (see Appendix B: Exposure Control Plan [ECP] Template). In other jurisdictions, written codes of practice or work procedures may also be required (see further Appendix 1 Legislation in the Enform Guideline *Controlling Chemical Hazards in the Oil and Gas Industry*).

IRP In any location where chemical exposures are indicated, consideration should be given to control measures that could further reduce or, ideally, eliminate all exposures. The hierarchy of controls should be considered in evaluating potential control measures (see further Introduction in the Enform Guideline *Controlling Chemical Hazards in the Oil and Gas Industry*).

Systematic and scientific monitoring of chemical exposures in specific work areas and specific operational tasks is critical for a number of reasons. With effective monitoring, controls can be applied much more precisely and their actual effectiveness properly measured. Well designed and targeted control measures are ultimately more cost effective in terms of an overall risk management strategy. They are also more likely to be fully applied by supervisors and workers implementing and/or maintaining these controls.

Occupational exposure levels can be measured by using small battery powered air sampler pumps equipped with charcoal tubes that collect all airborne hydrocarbons of C5 or greater. The tubes can then be analyzed in a laboratory to find how much of each chemical component was collected over a given time period. Pre-filters can be used to evaluate liquid mist content as well. This equipment can be used to collect samples at fixed points in key work areas (area sampling). Alternatively, workers can wear it as they carry out normal duties to measure average exposures during a full shift or during specific tasks. These procedures and other related evaluations of the workplace should be carried out by individuals trained and competent in monitoring procedures.

Companies should consider a systematic monitoring program that combines both baseline tests of exposure levels and routine monitoring. Baseline testing can establish exposure risks and assist in the development of effective control measures. Routine monitoring can then measure a company's performance against their exposure management program. For example, baseline testing would involve broader, rigorous testing with air sampling pumps. Routine monitoring may involve the use of passive absorption badges as a check on the effectiveness of controls in place. A systematic combination of baseline and subsequent testing is essential if companies are looking for continuous improvement in the reduction of exposure risk to their employees.

Companies using non water based drilling fluids may find it beneficial to develop a monitoring program that is based on an established model or set models for exposures. With this approach, a company may use either an industry initiated study or perform an in house monitoring initiative that would establish expected exposure ranges for specific locations and/or tasks on the lease site. Baseline models such as these would need to specify the type of drilling operation and the configuration of the equipment as well as the type of fluid or fluids that were used in the study.

This model or set of models then forms the base for anticipating exposures in future drilling operations. Companies adopting this approach should develop a formalized assessment process to determine when existing models are applicable and when new operations fall outside the parameters of the model. In the latter case additional monitoring may be required. Essentially, this is the application of management of change (MOC) practices to determine monitoring requirements on a go forward basis. The process envisioned here would consist of three basic steps.

First, for each new drilling program developed, a detailed assessment and/or checklist should be completed to establish whether the program is sufficiently aligned to the conditions of the established exposure model. If it is deemed as sufficiently equivalent, the exposure levels of the established models may be assumed to apply. It is important that this step is formalized as part of drilling program development and not simply assumed.

Second, where the assessment process and/or checklist indicates there are variants from the established model, further analysis is required to determine how these changes will impact the risk of exposure. Variants that may impact exposure risk include, but are not limited to, the following:

- Fluid type
- Fluid viscosity
- Fluid operating temperature
- Production fluids in the mixture

Other changes that should be subject to analysis to determine if additional monitoring is required include the introduction of the following:

- New processes
- Major equipment adjustments

- Significant changes to equipment layout or configurations
- New chemicals

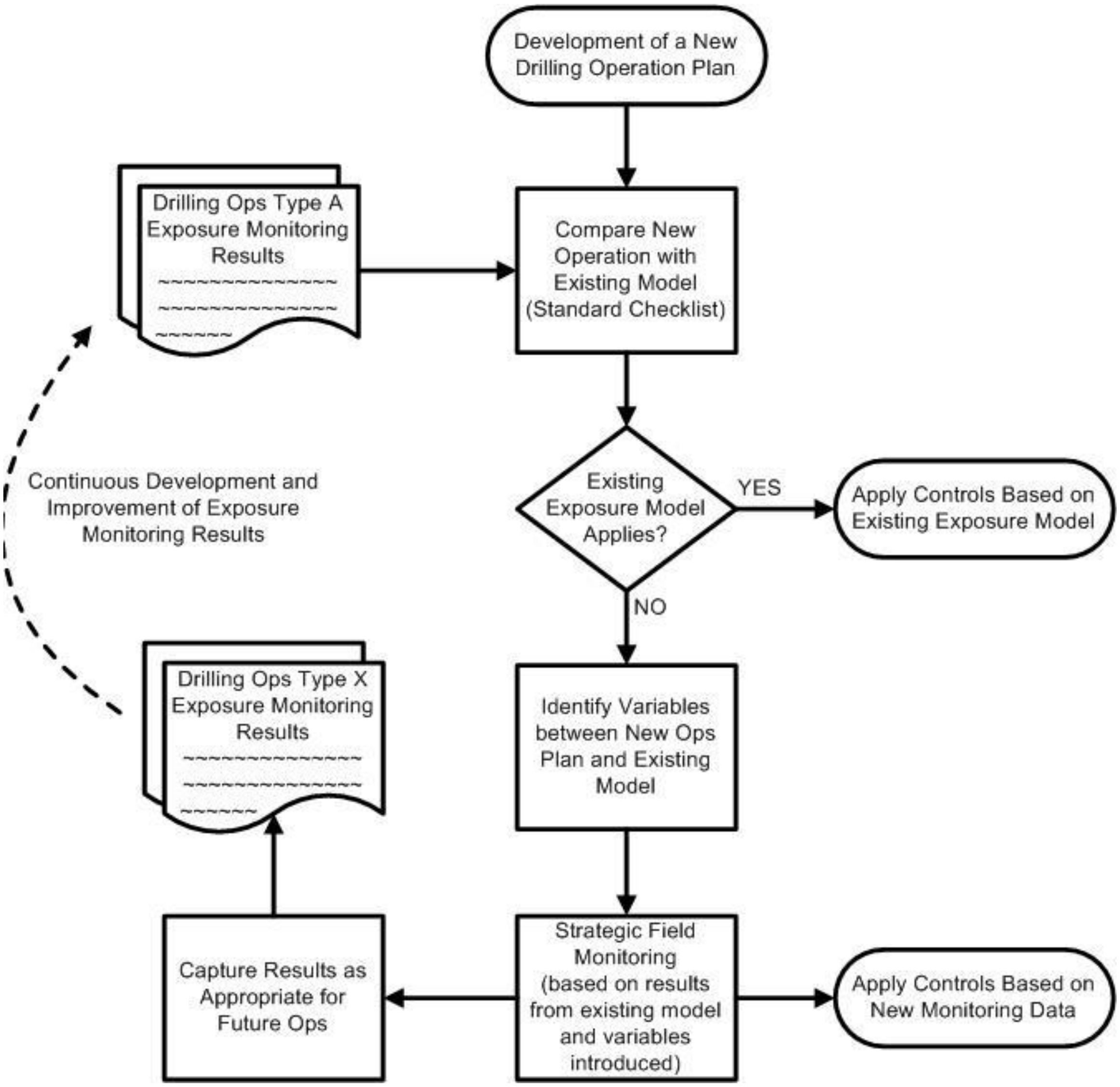
Third, where the need for additional monitoring established in step two, the established models may be used as a guide to targeted monitoring. Those work zones and tasks that were shown to present the greatest exposure risk in the existing model would, in most cases, be the ideal zones to target with monitoring with the new model (e.g., if the shaker area has proven to present the highest exposure hazard, this would be the best place to monitor if there were significant changes in the makeup of the fluid). Monitoring may also be targeted based on the specific nature of the change introduced to the drilling plan (e.g., in the vicinity of new equipment). These initial targeted monitoring results can then be used to decide if the exposure hazard has risen sufficiently to dictate further monitoring or if existing controls will suffice.

Companies that adopt this approach may find it valuable to standardize (as much as possible) their drilling programs into a manageable set of fluid programs and equipment configurations.

A summary of existing data shared with CAPP is presented in Appendix C. It is worth noting that this data was collected from open rigs drilling natural gas wells using Distillate 822 as the hydrocarbon based drilling fluid. Therefore, the use of other more volatile drilling fluids such as diesel, the use of different rig configurations such as enclosed mud tanks, or drilling different types of wells such as oil wells may impact exposures beyond what is indicated.

While inhalation exposure hazards have been the prime concern with non water based fluids to date, skin exposures may also be included in a monitoring program. This would require both a baseline assessment for new employees or at the start of an operation and inspection or monitoring at intervals thereafter.

Figure 7. A management of change assessment process to determine monitoring requirements



Appendix A: Applying the Enform Controlling Chemical Hazards Guideline (CCH) Methodology to a Drilling Project

The Enform Guideline *Controlling Chemical Hazards in the Oil and Gas Industry* (CCH) provides guidance on controlling chemical hazards in the context of multi-contractor oil and gas industry projects. In this appendix, the methodology outlined for managing chemicals in oil and gas operations from planning stage through the completion of front line work has been applied to the typical steps in drilling project. It is important for all parties to be engaged in the task of controlling chemical hazards. In the hierarchy of controls, elimination and substitution rank ahead of administrative controls and personal protective equipment (PPE). In the context of a drilling operation, these two controls are typically determined very early in the process, well before the drilling contractor and its front line workers (as well as other lease site workers) find themselves working with the selected chemicals. On the other end, administrative controls and PPE controls are only meaningful if applied as intended by front line supervisors and workers. Hazard assessment and control are an extended and repeated process that needs to be coordinated across the multiple parties that are involved in a drilling project. This appendix is designed to illustrate end to end chemical hazard management if applied with existing tools in the Controlling Chemical hazrds Guideline.

Color coding based on Enform CCH Guideline

🟦 **Planning Phase Participants**

🟥 **Implementation Phase Participants**

🟩 **Execution Phase Participants**

Drilling Engineer (Operator)

- Assigned project in a new area
- Provided initial geological assessment
- Discusses optimal mud program for local formation with supplier

Drilling Fluid Specialist (Drilling Fluid Supplier / "Mud Company")

- Recommends non water based drilling fluid

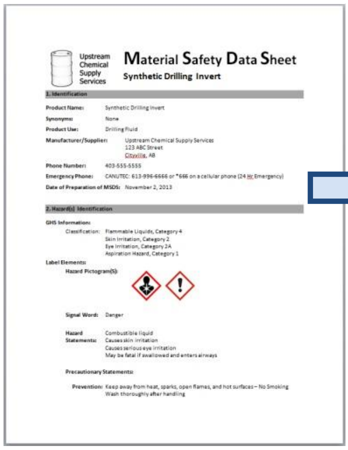
Drilling Engineer (Operator)

- Evaluates proposal from Supplier
    - Consults additional resources within company to confirm formation demands non water based fluid
    - Conducts chemical hazard assessment (includes factoring variables such as ambient and flowline temperatures and anticipated flashpoint)
    - Cost of risk and required controls for proposed fluid (base + additives) factored into project decision-making
    - Hand-off to Drilling Superintendent once decision is made

Control Considered:

Elimination/
Substitution

Supplier-provided MSDS



Upstream Chemical Supply Services

Material Safety Data Sheet

Synthetic Drilling Invert

1. Identification

Product Name: Synthetic Drilling Invert
Synonyms: None
Product Use: Drilling Fluid
Manufacturer/Supplier: Upstream Chemical Supply Services
123 ABC Street
Cityville, AB
Phone Number: 403-555-5555
Emergency Phone: CANUTEC: 613-996-6666 or *666 on a cellular phone (24 Hr Emergency)
Date of Preparation of MSDS: November 2, 2013

2. Hazard(s) Identification

GHS Information:
Classification: Flammable Liquids, Category 4
Skin Irritation, Category 2
Eye Irritation, Category 2A
Aspiration Hazard, Category 1
Label Elements:
Hazard Pictogram(S):

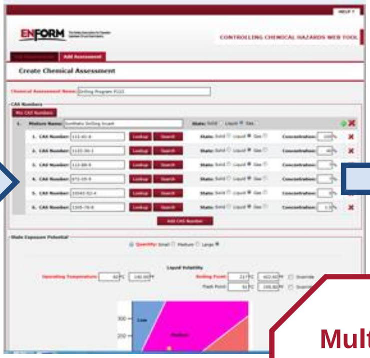
Signal Word: Danger

Hazard Statements: Combustible liquid
Causes skin irritation
Causes serious eye irritation
May be fatal if swallowed and enters airways

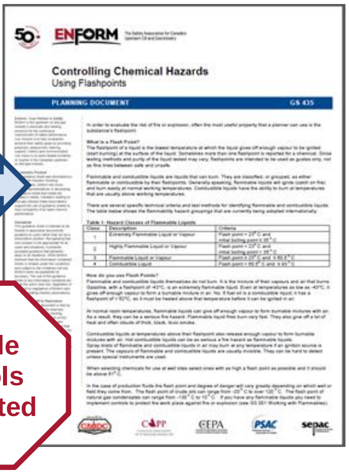
Precautionary Statements:

Prevention: Keep away from heat, sparks, open flames, and hot surfaces – No Smoking
Wash thoroughly after handling

Controlling Chemical Hazards (CCH) Web Tool



Guidance Documents from CCH Web Tool



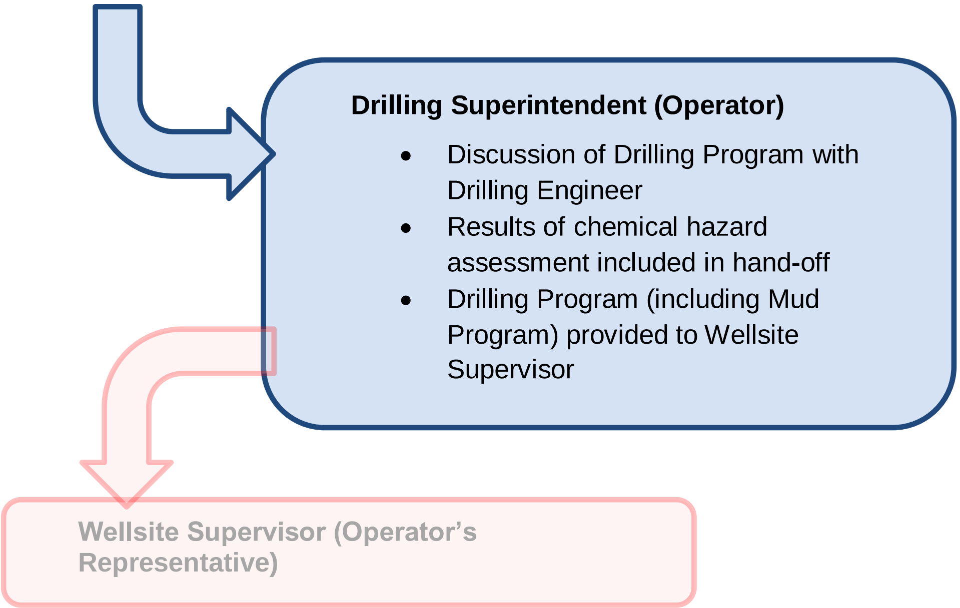
ENFORM

Controlling Chemical Hazards
Using Flashpoints

PLANNING DOCUMENT GS 435

Table 1: Hazard Classes of Flammable Liquids

Multiple Controls Suggested



Drilling Superintendent (Operator)

- Discussion of Drilling Program with Drilling Engineer
- Results of chemical hazard assessment included in hand-off
- Drilling Program (including Mud Program) provided to Wellsite Supervisor

Wellsite Supervisor (Operator's Representative)

A Planner's Checklist (from CCH Guideline, 48-50)

Step 1

☐ Have you identified all operations or areas that will involve chemicals and chemical exposure to workers?

☐ Have you considered equipment design and layout?

Step 2

☐ Have you identified the chemical control responsibilities?

☐ Have you confirmed who is responsible for each aspect of the chemical control plan?

☐ Have you ensured communication between operator / chemical suppliers, operator / service contractors and chemical suppliers / service contractors takes place in identifying and mitigating potential chemical hazards? (See CCH Guideline, Appendix 2 for Start-Up Meeting Template.)

Step 3

☐ Have you identified all chemicals and chemical mixtures to be used?

☐ Have you identified mixtures and blends of chemicals?

☐ Have you collected, reviewed, and provided the required information (MSDSs and guidance sheets) for each of the chemicals to be used?

☐ Have you designed the safety protocol for chemical control?

Step 4

☐ Have you assessed the chemicals in regards to:

  - Its properties (e.g., flammable, health hazards)?
  - Where it is being used?
  - How much is being used?
  - The duration of exposure to the worker?
  - How the workers will be exposed (e.g., inhalation, skin absorption, etc.)?

Step 5

☐ Have you evaluated and analyzed the chemical hazard?

☐ Have you done one of the following:

- Quantified risk through a hazard assessment matrix?
- Quantified risk through a control-banding option?
- Quantified risk through the controlling chemical hazard web tool (www.enform.ca)?
- Quantified risk with the help of a chemical specialist (e.g., occupational hygienist or health or chemical specialist)?

Step 6

☐ Have you selected the appropriate control (from the hierarchy of controls)?

☐ Have you considered elimination or substitution?

☐ Have you considered and/or designed and implemented engineering controls?

☐ Have you considered and communicated administrative controls?

☐ Have you considered and communicated the appropriate PPE to be used?

☐ Have you co-operated with service contractors to confirm that the appropriate hazard controls are in place, are effective, and comply with health and safety regulations?

☐ Have you provided all relevant chemical hazardous information (e.g., MSDSs) to educate workers about potential risks for all chemicals, including produced and recycled fluids?

☐ Have you ensured that service contractors and chemical suppliers are providing adequate support and training about hazard assessment and controls to their workers and contractors?

Step 7

☐ Have you confirmed that these controls work?

☐ Have you confirmed with implementers that the controls are working and effective?

☐ Have you confirmed, through MOC, that the controls work?

☐ Have you continued informing, instructing, and training on the chemicals and the controls for those chemicals?

☐ Have you utilized formal training? On-the-job training? Both?

☐ Have you validated competencies on site? Over time?

☐ Have you kept assessment reports regarding decisions about risk and the controls selected?

☐ Have you ensured regular maintenance is done on controls?

Drilling Superintendent (Operator)

Wellsite Supervisor (Operator's Representative)

- Together with Drilling Superintendent determine equipment and service requirements
- Discussion of chemical hazard assessment and exposure control plan requirements
- Manages the coordination of Drilling Contractor and Vendors

Controls Considered:
Engineering
Administrative

Wellsite Supervisor (Operator's Representative)

Drilling Contractor Supervisor(s) (Drilling Contractor)

- Coordinated review of ECP that will be kept at wellsite, including:
  - Identify hazards and risk to workers
  - Required engineering, administrative and PPE controls
- Reviews tables in Section 4 of IRP 14 to assist in identifying any possible additional onsite hazards and controls, including:
  - Chemical Exposure Scenarios
  - Safety Hazards

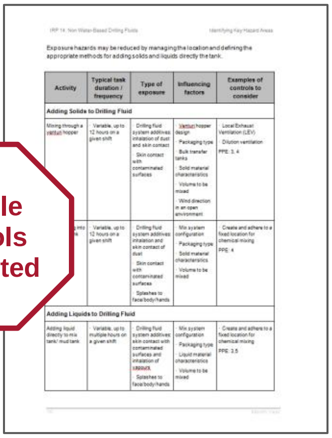
ECP Template provided within Enform's CCH Guideline
&
IRP 14.4 Tables

Exposure Control Plan

Drilling Program: P123
Lease Site 111A-007
Wildwoods, BC

Created: 12-12-2012
Last Revised: 10-10-2013

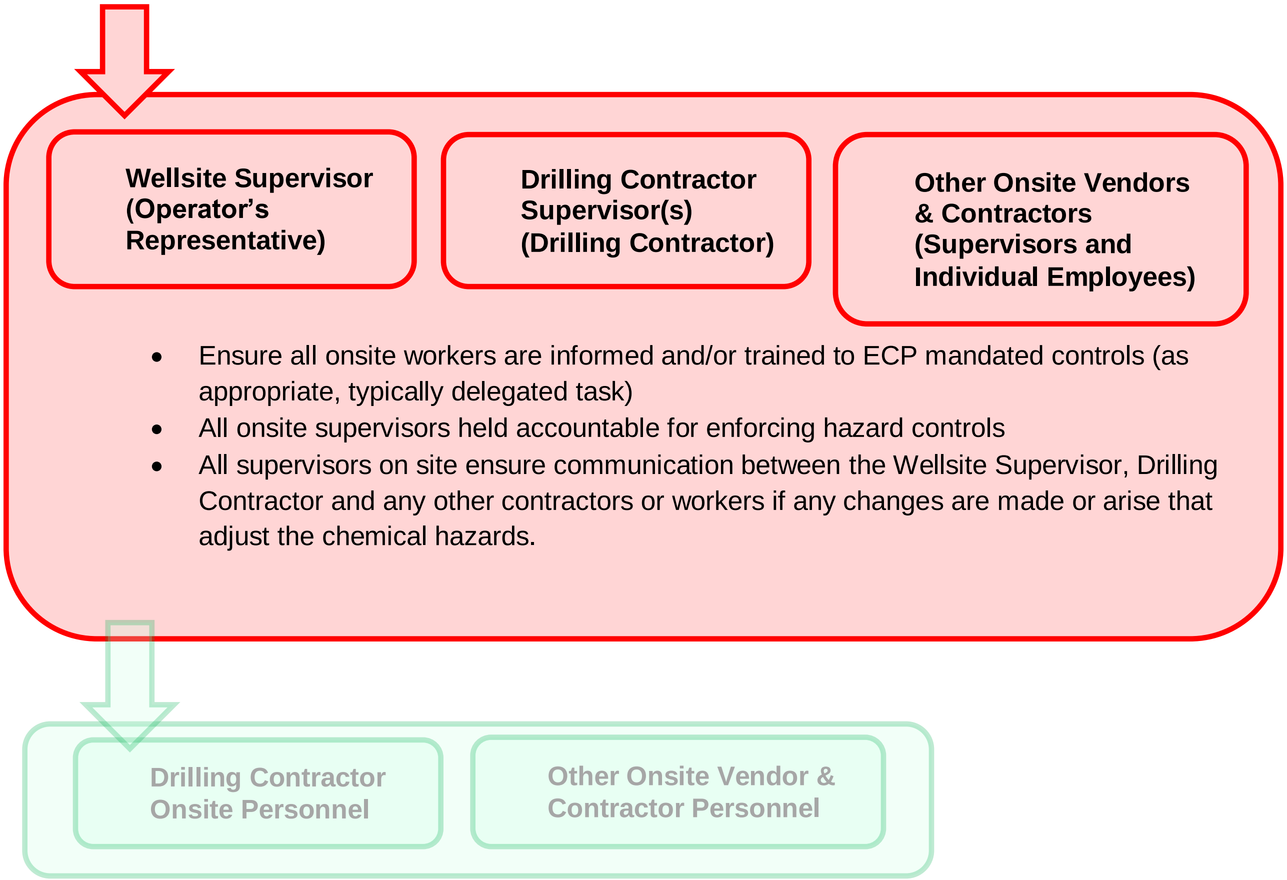
Multiple Controls Suggested



IRP 14: Non Water-Based Drilling Fluids
Identifying Key Hazard Areas

Exposure hazards may be reduced by managing the location and defining the appropriate methods for adding solids and liquids directly the tank.

Activity	Typical task duration / frequency	Type of exposure	Influencing factors	Examples of controls to consider
Adding Solids to Drilling Fluid				
Mixing through a venturi hopper	· Variable, up to 12 hours on a given shift	· Drilling fluid system additives: inhalation of dust and skin contact · Skin contact with contaminated surfaces	· Venturi hopper design · Packaging type · Bulk transfer tanks · Solid material characteristics · Volume to be mixed · Wind direction in an open environment	· Local Exhaust Ventilation (LEV) · Dilution ventilation PPE: 3, 4
[illegible]	· Variable, up to 12 hours on a given shift	· Drilling fluid system additives: inhalation and skin contact of dust · Skin contact with contaminated surfaces · Splashes to face/body/hands	· Mix system configuration · Packaging type · Solid material characteristics · Volume to be mixed	· Create and adhere to a fixed location for chemical mixing PPE: 4
Adding Liquids to Drilling Fluid				
Adding liquid directly to mix tank/ mud tank	· Variable, up to multiple hours on a given shift	· Drilling fluid system additives: skin contact with contaminated surfaces and inhalation of vapours · Splashes to face/body/hands	· Mix system configuration · Packaging type · Liquid material characteristics · Volume to be mixed	· Create and adhere to a fixed location for chemical mixing PPE: 3,5



- Ensure all onsite workers are informed and/or trained to ECP mandated controls (as appropriate, typically delegated task)
- All onsite supervisors held accountable for enforcing hazard controls
- All supervisors on site ensure communication between the Wellsite Supervisor, Drilling Contractor and any other contractors or workers if any changes are made or arise that adjust the chemical hazards.

A Supervisor's Checklist (from CCH Guideline, 62)

As a supervisor you have the unique ability to liaise between the planners and the workers. You have the authority to receive the chemical information from the planners and the responsibility to pass that information on to the workers.

General

- ☐ Have you initiated and run a start-up meeting that includes all necessary personnel? (See CCH Guideline, Appendix 2.)
- ☐ Have you provided appropriate MSDS and guidance sheets?
- ☐ Have you complied with WHMIS labelling requirements?
- ☐ Have you organized and implemented on-site hazard assessments?
- ☐ Have you ensured communication flow between shifts, contractors, etc.?
- ☐ Have you ensured availability and worker knowledge of specific PPE?
- ☐ Have you enforced the safety protocol for chemical control?

Specific

- ☐ Are you aware of the specific chemicals being used on site?
- ☐ Have you received the necessary information on the chemicals being used on site (e.g., MSDS, guidance sheets, etc.)?
- ☐ Have you reviewed and shared the chemical information to all participants handling, storing, or working with the chemical?
- ☐ Have you assisted in the decision to blend or mix chemicals?
- ☐ Have you completed a hazard assessment on the new blend or mix?
- ☐ Have you determined if there are hazards associated with the new blend or mix?
- ☐ Have you established controls for these hazards?
- ☐ Have you communicated these controls to all participants involved?

Wellsite Supervisor (Operator's Representative)

Drilling Contractor Supervisor(s) (Drilling Contractor)

Other Onsite Vendors & Contractors (Supervisors and Individual Employees)

Drilling Contractor Onsite Personnel

Other Onsite Vendor & Contractor Personnel

- Information on chemical hazards and controls provided to all workers on site, including:
    - CCH Worker's Flip Guide
    - Guidance Documents aimed at workers
    - Location of MSDS and ECP
- Workers ensure engineering controls are applied/functioning as designed, administrative controls are being followed, and required PPE is worn
- Workers "stop and ask" whenever they have questions or concerns on chemicals or chemical exposure are raised
- Workers report any concerns or observed changes

ECP and MSDS Documents Available for Workers

Exposure Control Plan

Upstream Chemical Supply Services

Material Safety Data Sheet

Synthetic Drilling Invert

1. Identification

Product Name: Synthetic Drilling Invert
Synonyms: None
Product Use: Drilling Fluid
Manufacturer/Supplier: Upstream Chemical Supply Services
123 ABC Street
Cityville, AB
Phone Number: 403-555-5555
Emergency Phone: CANUTEC: 613-996-6666 or *666 on a cellular phone (24 Hr Emergency)
Date of Preparation of MSDS: November 2, 2013

2. Hazard(s) Identification

GHS Information:
Classification: Flammable Liquids, Category 4
Skin Irritation, Category 2
Eye Irritation, Category 2A
Aspiration Hazard, Category 1
Label Elements:
Hazard Pictogram(S):

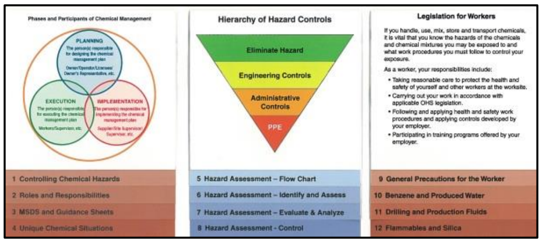
Signal Word: Danger

Hazard Statements: Combustible liquid
Causes skin irritation
Causes serious eye irritation
May be fatal if swallowed and enters airways

Precautionary Statements:

Prevention: Keep away from heat, sparks, open flames, and hot surfaces – No Smoking
Wash thoroughly after handling

CCH Worker's Flip Guide and
CCH Guidance Docs relevant for Workers



Phases and Participants of Chemical Management

Hierarchy of Hazard Controls

Legislation for Workers

If you handle, use, mix, store and transport chemicals, it is vital that you know the hazards of the chemicals and chemical mixtures you may be exposed to and what work procedures you must follow to control your exposure.

As a worker, your responsibilities include:

- Taking reasonable care to protect the health and safety of yourself and other workers at the worksite.
- Carrying out your work in accordance with applicable OHS legislation.
- Following and applying health and safety work procedures and applying controls developed by your employer.
- Participating in training programs offered by your employer.

ENFORM

Controlling Chemical Hazards
How to Reduce Skin Contact with Hazardous Substances

PROCESS DOCUMENT CONTROL APPROACH S GS 400

Who Should Use?

Selection

Planning and preparation

What needs protecting - what skin is likely to be exposed?

Controls Applied:
Engineering
Administrative
PPE

A Worker's Checklist (from CCH Guideline, 76)*

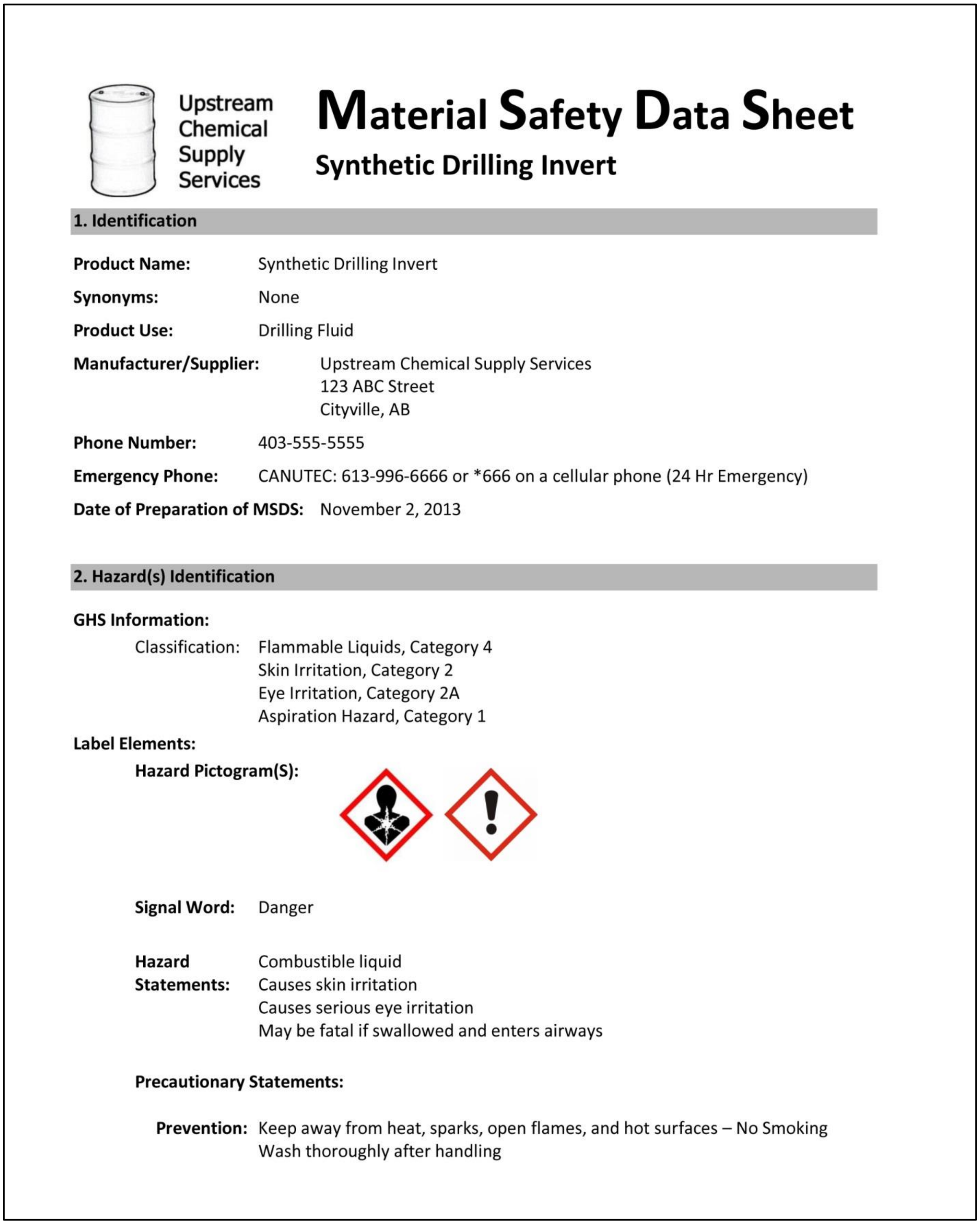
If you do not know what chemical substance you are working with and how to handle it safely, stop and ask!

- ☐ Ask your employer about the risks, what precautions to take and what to do in an emergency.
- ☐ Follow your employer's safe work procedures.
- ☐ Avoid directly breathing in chemical vapours.
- ☐ Avoid getting chemical directly on your skin.
- ☐ Use the ventilation equipment and PPE provided—e.g., gloves, masks, goggles (see GS405 – PPE).
- ☐ Wear gloves that will protect you from the chemical you're handling. For example, when dealing with benzene, wear benzene-resistant materials; do not wear natural rubber gloves, as rubber absorbs benzene (see GS404 – Gloves).
- ☐ Report to your employer or safety representative if you discover any damaged or defective ventilation systems or protective equipment at your workplace.
- ☐ Make sure the room is well ventilated and any extraction or air supply is switched on and working.
- ☐ Look for signs of damage, wear, or poor operation of any equipment used and report them to your supervisor. Don't continue working if you think a problem exists.
- ☐ Wash your hands before and after eating, drinking, and using the bathroom.
- ☐ Don't use solvent to clean your skin.
- ☐ Clean up spills immediately. Contain or absorb liquids with granules or mats; use a vacuum cleaner or wet mop to clean up solids. Dispose of spilled substances safely.

*Note that frontline supervisors may benefit from a checklist adapted from components selected from both the Supervisors Checklist (see above) and this Worker's Checklist.

Samples of documents and tools referenced in drilling scenario

Supplier-Provided MSDS (for base and all additives):



Upstream
Chemical
Supply
Services

Material Safety Data Sheet

Synthetic Drilling Invert

1. Identification

Product Name: Synthetic Drilling Invert

Synonyms: None

Product Use: Drilling Fluid

Manufacturer/Supplier:
Upstream Chemical Supply Services
123 ABC Street
Cityville, AB

Phone Number: 403-555-5555

Emergency Phone: CANUTEC: 613-996-6666 or *666 on a cellular phone (24 Hr Emergency)

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Label Elements:

Hazard Pictogram(S):

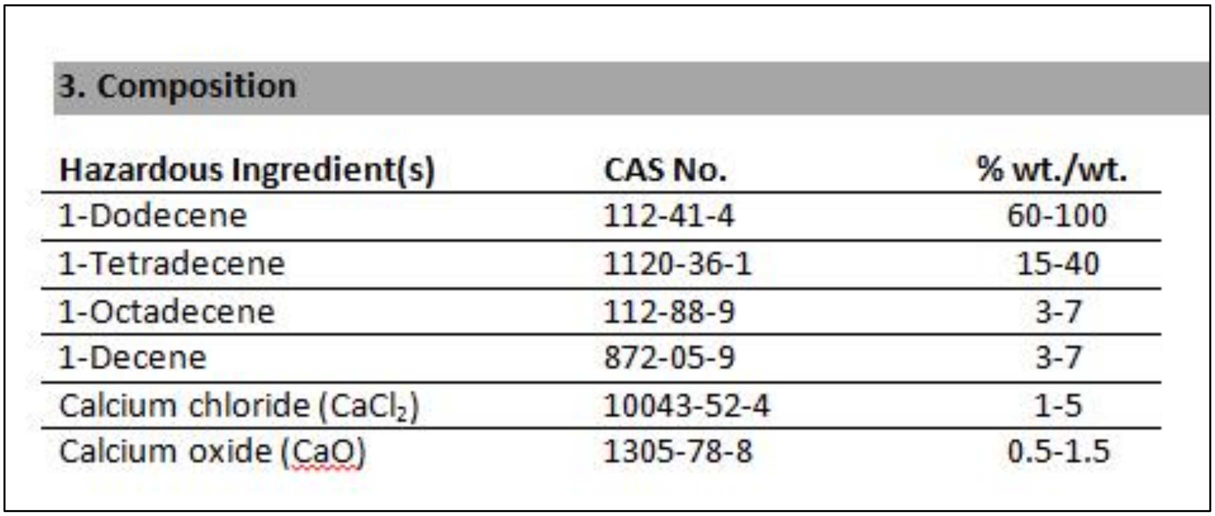
Signal Word: Danger

Hazard Statements:
Combustible liquid
Causes skin irritation
Causes serious eye irritation
May be fatal if swallowed and enters airways

Precautionary Statements:

Prevention:
Keep away from heat, sparks, open flames, and hot surfaces – No Smoking
Wash thoroughly after handling

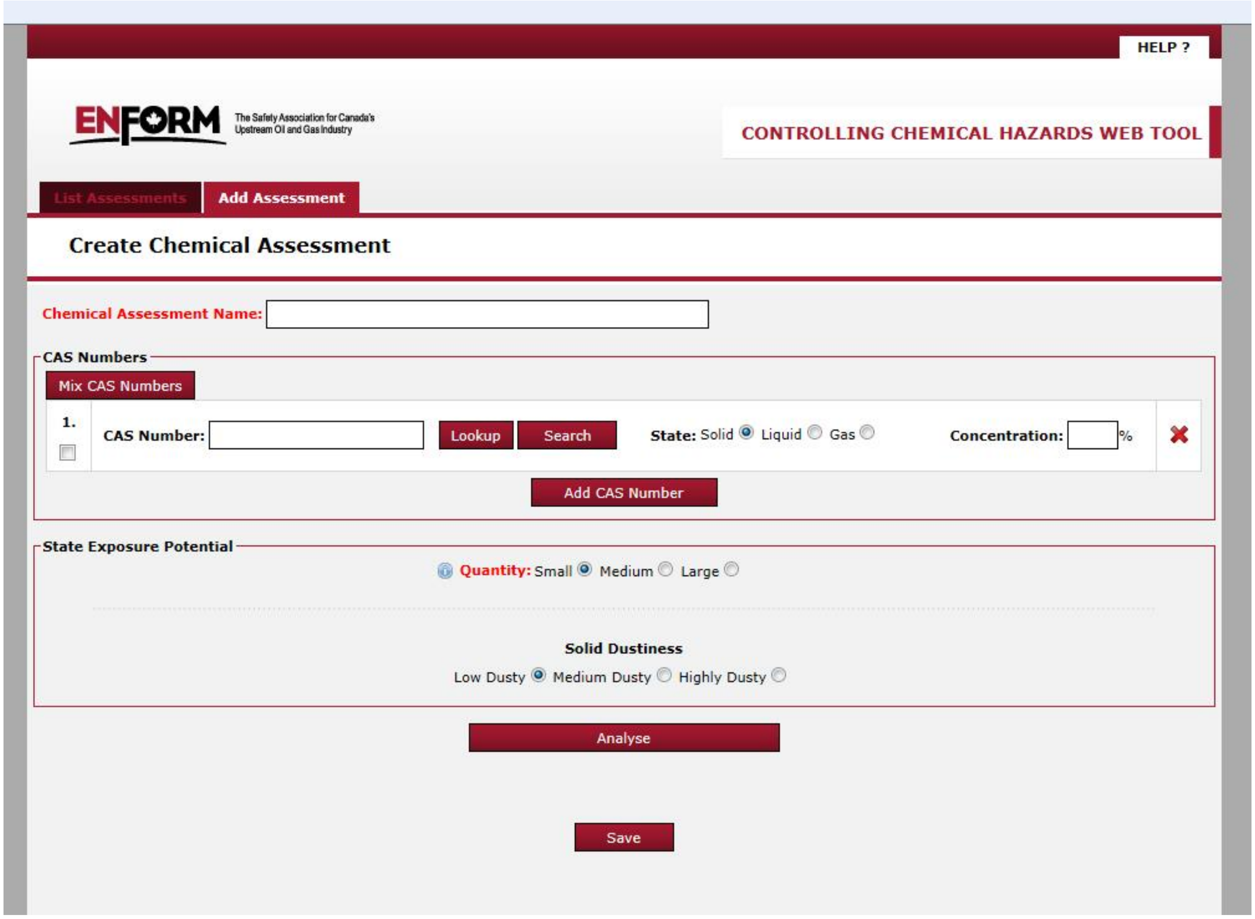
MSDS provides composition details including CAS number(s):



3. Composition

Hazardous Ingredient(s)	CAS No.	% wt./wt.
1-Dodecene	112-41-4	60-100
1-Tetradecene	1120-36-1	15-40
1-Octadecene	112-88-9	3-7
1-Decene	872-05-9	3-7
Calcium chloride ($CaCl_2$)	10043-52-4	1-5
Calcium oxide (CaO)	1305-78-8	0.5-1.5

Controlling Chemical Hazards (CCH) Web Tool:

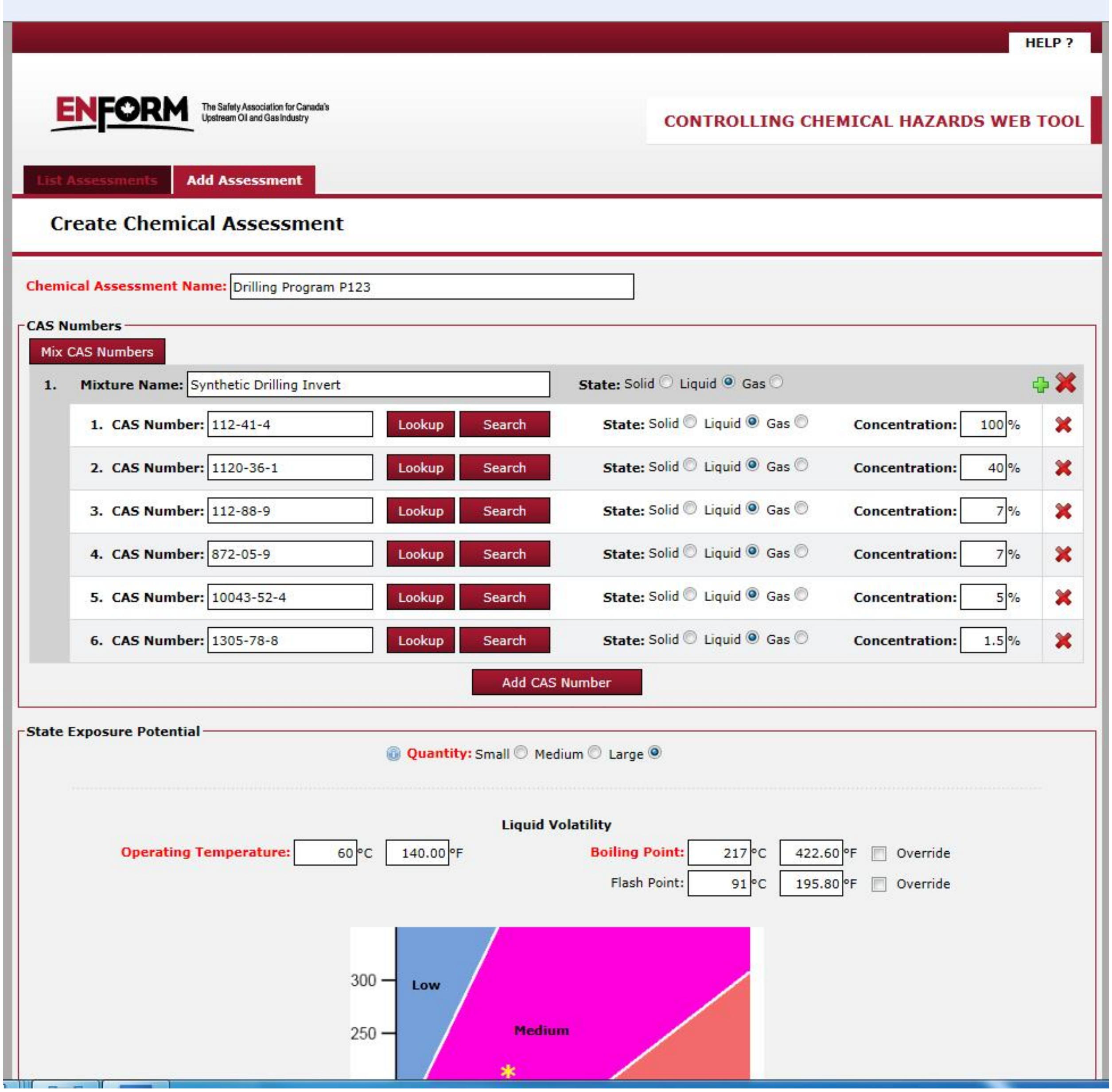


State: Solid ● Liquid ○ Gas ○

Quantity: Small ● Medium ○ Large ○

Low Dusty ● Medium Dusty ○ Highly Dusty ○

CCH Web Tool populated with information from MSDS(s)



Create Chemical Assessment

Chemical Assessment Name: Drilling Program P123

CAS Numbers

1. **Mixture Name:** Synthetic Drilling Invert   **State:** Solid ○ Liquid ● Gas ○

1. **CAS Number:** 112-41-4	**State:** Solid ○ Liquid ● Gas ○	**Concentration:** 100 %
2. **CAS Number:** 1120-36-1	**State:** Solid ○ Liquid ● Gas ○	**Concentration:** 40 %
3. **CAS Number:** 112-88-9	**State:** Solid ○ Liquid ● Gas ○	**Concentration:** 7 %
4. **CAS Number:** 872-05-9	**State:** Solid ○ Liquid ● Gas ○	**Concentration:** 7 %
5. **CAS Number:** 10043-52-4	**State:** Solid ○ Liquid ● Gas ○	**Concentration:** 5 %
6. **CAS Number:** 1305-78-8	**State:** Solid ○ Liquid ● Gas ○	**Concentration:** 1.5 %

State Exposure Potential

Quantity: Small ○ Medium ○ Large ●

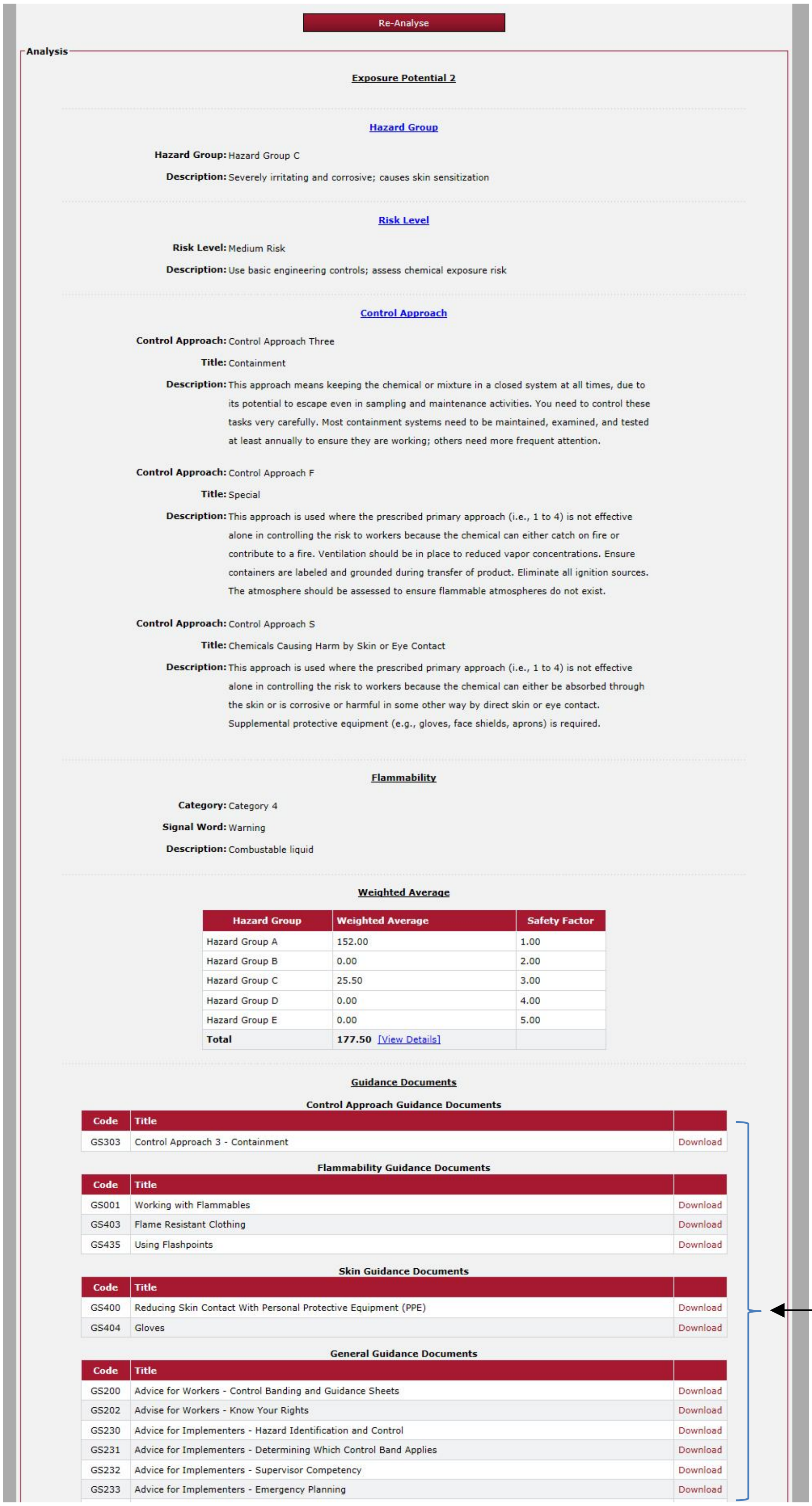
Liquid Volatility

Operating Temperature: 60 °C 140.00 °F

Boiling Point: 217 °C 422.60 °F ☐ Override

Flash Point: 91 °C 195.80 °F ☐ Override

CCH Web Tool provides analysis (example only):



Exposure Potential 2

Hazard Group

Hazard Group: Hazard Group C

Description: Severely irritating and corrosive; causes skin sensitization

Risk Level

Risk Level: Medium Risk

Description: Use basic engineering controls; assess chemical exposure risk

Control Approach

Control Approach: Control Approach Three

Title: Containment

Description: This approach means keeping the chemical or mixture in a closed system at all times, due to its potential to escape even in sampling and maintenance activities. You need to control these tasks very carefully. Most containment systems need to be maintained, examined, and tested at least annually to ensure they are working; others need more frequent attention.

Control Approach: Control Approach F

Title: Special

Description: This approach is used where the prescribed primary approach (i.e., 1 to 4) is not effective alone in controlling the risk to workers because the chemical can either catch on fire or contribute to a fire. Ventilation should be in place to reduced vapor concentrations. Ensure containers are labeled and grounded during transfer of product. Eliminate all ignition sources. The atmosphere should be assessed to ensure flammable atmospheres do not exist.

Control Approach: Control Approach S

Title: Chemicals Causing Harm by Skin or Eye Contact

Description: This approach is used where the prescribed primary approach (i.e., 1 to 4) is not effective alone in controlling the risk to workers because the chemical can either be absorbed through the skin or is corrosive or harmful in some other way by direct skin or eye contact. Supplemental protective equipment (e.g., gloves, face shields, aprons) is required.

Flammability

Category: Category 4

Signal Word: Warning

Description: Combustible liquid

Weighted Average

Hazard Group	Weighted Average	Safety Factor
Hazard Group A	152.00	1.00
Hazard Group B	0.00	2.00
Hazard Group C	25.50	3.00
Hazard Group D	0.00	4.00
Hazard Group E	0.00	5.00
Total	**177.50** [View Details]	

Guidance Documents

Control Approach Guidance Documents

Code	Title	
GS303	Control Approach 3 - Containment	Download

Flammability Guidance Documents

Code	Title	
GS001	Working with Flammables	Download
GS403	Flame Resistant Clothing	Download
GS435	Using Flashpoints	Download

Skin Guidance Documents

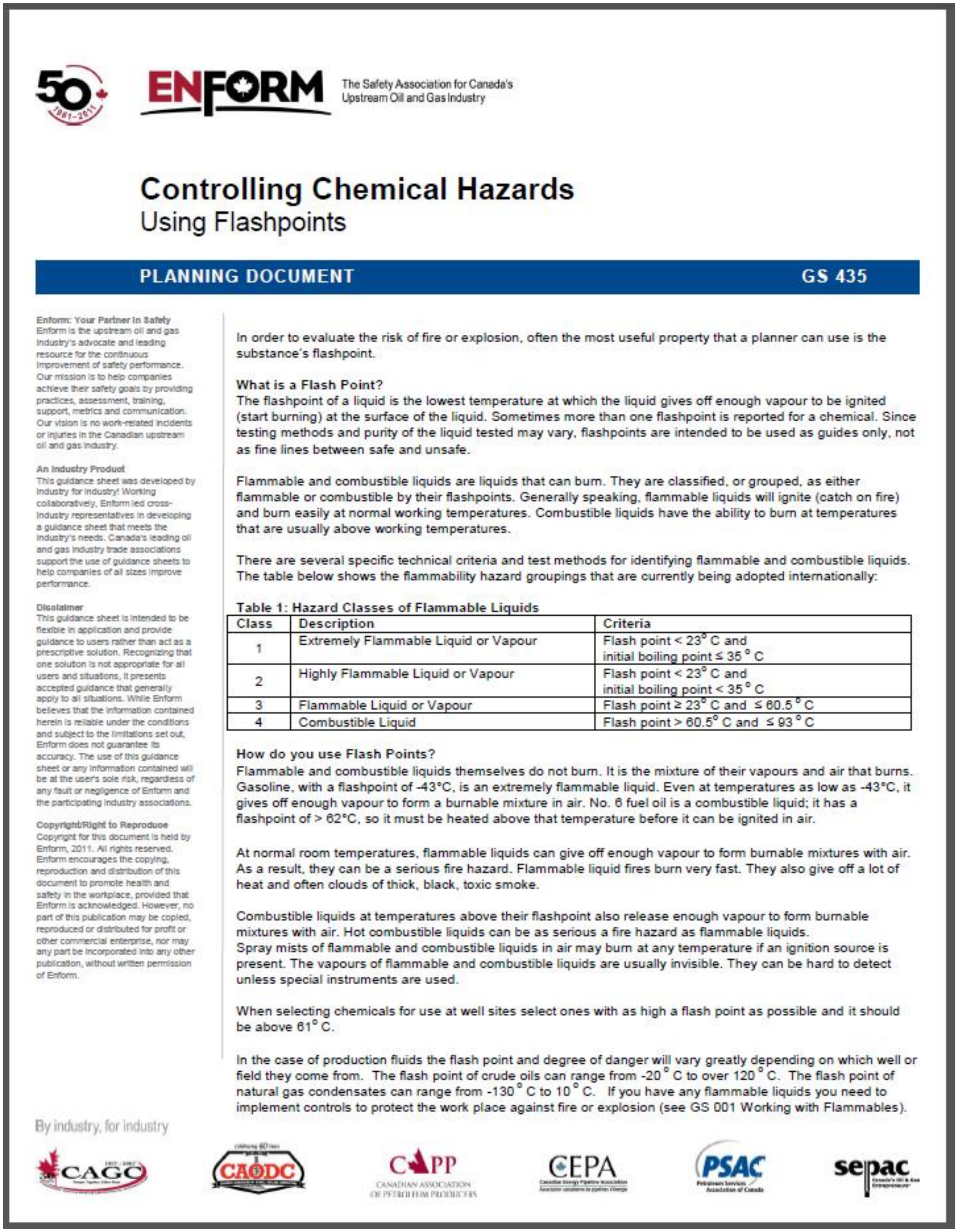
Code	Title	
GS400	Reducing Skin Contact With Personal Protective Equipment (PPE)	Download
GS404	Gloves	Download

General Guidance Documents

Code	Title	
GS200	Advice for Workers - Control Banding and Guidance Sheets	Download
GS202	Advise for Workers - Know Your Rights	Download
GS230	Advice for Implementers - Hazard Identification and Control	Download
GS231	Advice for Implementers - Determining Which Control Band Applies	Download
GS232	Advice for Implementers - Supervisor Competency	Download
GS233	Advice for Implementers - Emergency Planning	Download

Links to downloadable Guidance Documents

Sample Guidance Document from CCH Web Tool:



ENFORM The Safety Association for Canada's Upstream Oil and Gas Industry

Controlling Chemical Hazards

Using Flashpoints

PLANNING DOCUMENT **GS 435**

Enform: Your Partner In Safety
Enform is the upstream oil and gas industry's advocate and leading resource for the continuous improvement of safety performance. Our mission is to help companies achieve their safety goals by providing practices, assessment, training, support, metrics and communication. Our vision is no work-related incidents or injuries in the Canadian upstream oil and gas industry.

An Industry Product
This guidance sheet was developed by industry for industry! Working collaboratively, Enform led cross-industry representatives in developing a guidance sheet that meets the industry's needs. Canada's leading oil and gas industry trade associations support the use of guidance sheets to help companies of all sizes improve performance.

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In order to evaluate the risk of fire or explosion, often the most useful property that a planner can use is the substance's flashpoint.

What is a Flash Point?
The flashpoint of a liquid is the lowest temperature at which the liquid gives off enough vapour to be ignited (start burning) at the surface of the liquid. Sometimes more than one flashpoint is reported for a chemical. Since testing methods and purity of the liquid tested may vary, flashpoints are intended to be used as guides only, not as fine lines between safe and unsafe.

Flammable and combustible liquids are liquids that can burn. They are classified, or grouped, as either flammable or combustible by their flashpoints. Generally speaking, flammable liquids will ignite (catch on fire) and burn easily at normal working temperatures. Combustible liquids have the ability to burn at temperatures that are usually above working temperatures.

There are several specific technical criteria and test methods for identifying flammable and combustible liquids. The table below shows the flammability hazard groupings that are currently being adopted internationally:

Table 1: Hazard Classes of Flammable Liquids

Class	Description	Criteria
1	Extremely Flammable Liquid or Vapour	Flash point < 23° C and initial boiling point ≤ 35 ° C
2	Highly Flammable Liquid or Vapour	Flash point < 23° C and initial boiling point < 35 ° C
3	Flammable Liquid or Vapour	Flash point ≥ 23° C and ≤ 60.5 ° C
4	Combustible Liquid	Flash point > 60.5° C and ≤ 93 ° C

How do you use Flash Points?
Flammable and combustible liquids themselves do not burn. It is the mixture of their vapours and air that burns. Gasoline, with a flashpoint of -43°C, is an extremely flammable liquid. Even at temperatures as low as -43°C, it gives off enough vapour to form a burnable mixture in air. No. 6 fuel oil is a combustible liquid; it has a flashpoint of > 62°C, so it must be heated above that temperature before it can be ignited in air.

At normal room temperatures, flammable liquids can give off enough vapour to form burnable mixtures with air. As a result, they can be a serious fire hazard. Flammable liquid fires burn very fast. They also give off a lot of heat and often clouds of thick, black, toxic smoke.

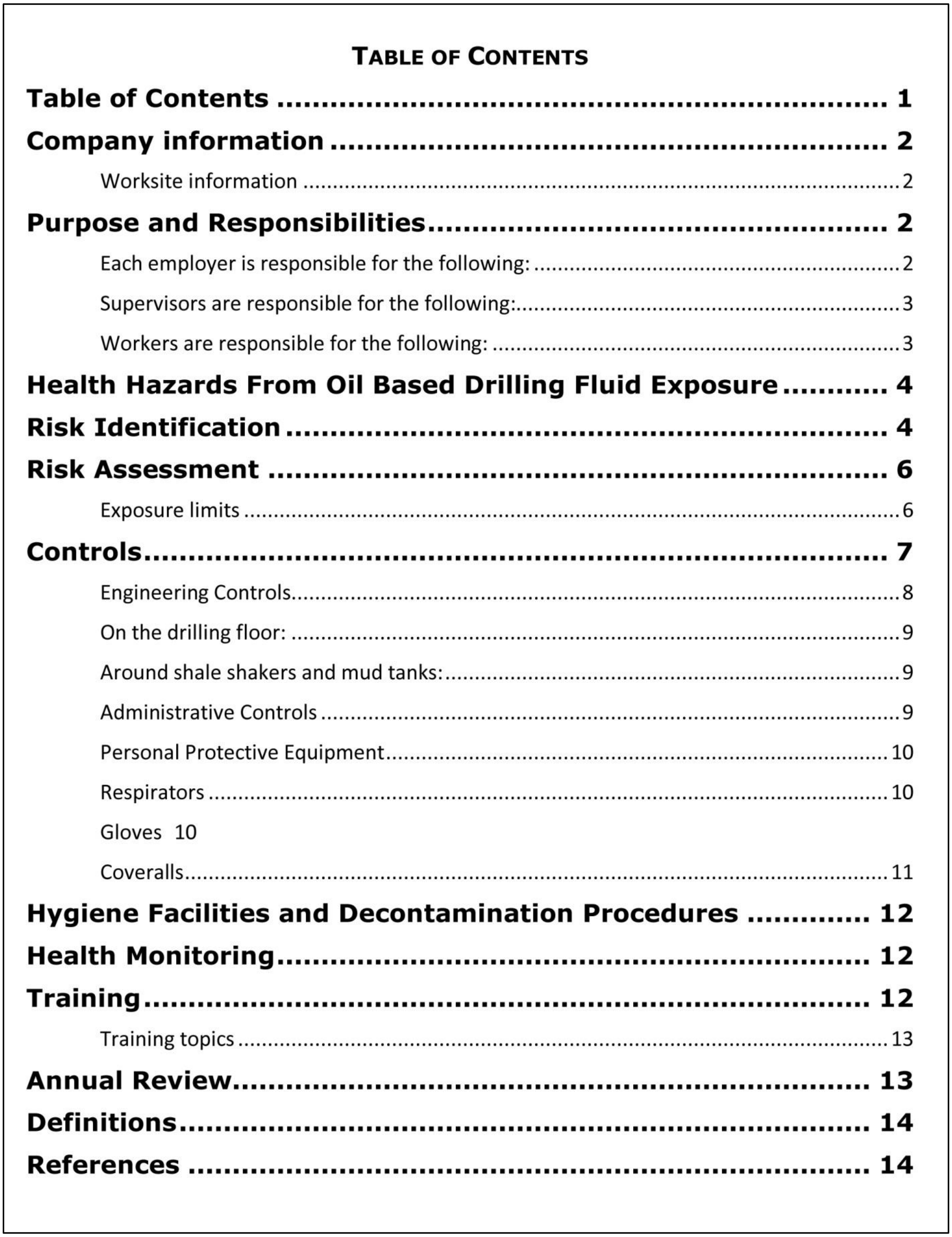
Combustible liquids at temperatures above their flashpoint also release enough vapour to form burnable mixtures with air. Hot combustible liquids can be as serious a fire hazard as flammable liquids.
Spray mists of flammable and combustible liquids in air may burn at any temperature if an ignition source is present. The vapours of flammable and combustible liquids are usually invisible. They can be hard to detect unless special instruments are used.

When selecting chemicals for use at well sites select ones with as high a flash point as possible and it should be above 61° C.

In the case of production fluids the flash point and degree of danger will vary greatly depending on which well or field they come from. The flash point of crude oils can range from -20 ° C to over 120 ° C. The flash point of natural gas condensates can range from -130 ° C to 10 ° C. If you have any flammable liquids you need to implement controls to protect the work place against fire or explosion (see GS 001 Working with Flammables).

By industry, for industry

Exposure Control Plan (Table of Contents):



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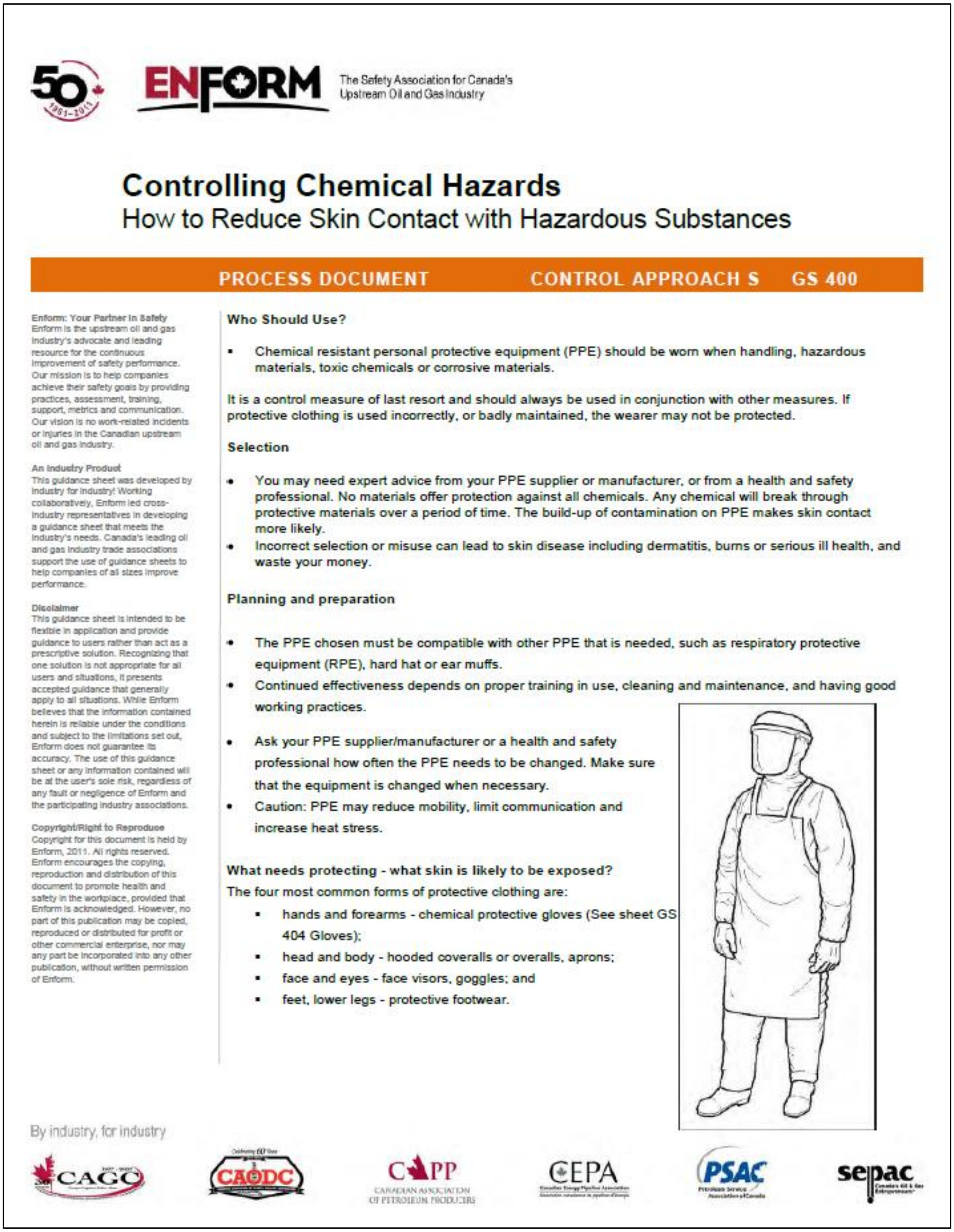
Example of Guidance Document with Relevance for Front Line Workers:



The Safety Association for Canada's Upstream Oil and Gas Industry

Controlling Chemical Hazards

How to Reduce Skin Contact with Hazardous Substances

PROCESS DOCUMENT **CONTROL APPROACH S** **GS 400**

Who Should Use?

- Chemical resistant personal protective equipment (PPE) should be worn when handling, hazardous materials, toxic chemicals or corrosive materials.

It is a control measure of last resort and should always be used in conjunction with other measures. If protective clothing is used incorrectly, or badly maintained, the wearer may not be protected.

Selection

- You may need expert advice from your PPE supplier or manufacturer, or from a health and safety professional. No materials offer protection against all chemicals. Any chemical will break through protective materials over a period of time. The build-up of contamination on PPE makes skin contact more likely.
- Incorrect selection or misuse can lead to skin disease including dermatitis, burns or serious ill health, and waste your money.

Planning and preparation

- The PPE chosen must be compatible with other PPE that is needed, such as respiratory protective equipment (RPE), hard hat or ear muffs.
- Continued effectiveness depends on proper training in use, cleaning and maintenance, and having good working practices.
- Ask your PPE supplier/manufacturer or a health and safety professional how often the PPE needs to be changed. Make sure that the equipment is changed when necessary.
- Caution: PPE may reduce mobility, limit communication and increase heat stress.

What needs protecting - what skin is likely to be exposed?

The four most common forms of protective clothing are:

- hands and forearms - chemical protective gloves (See sheet GS 404 Gloves);
- head and body - hooded coveralls or overalls, aprons;
- face and eyes - face visors, goggles; and
- feet, lower legs - protective footwear.

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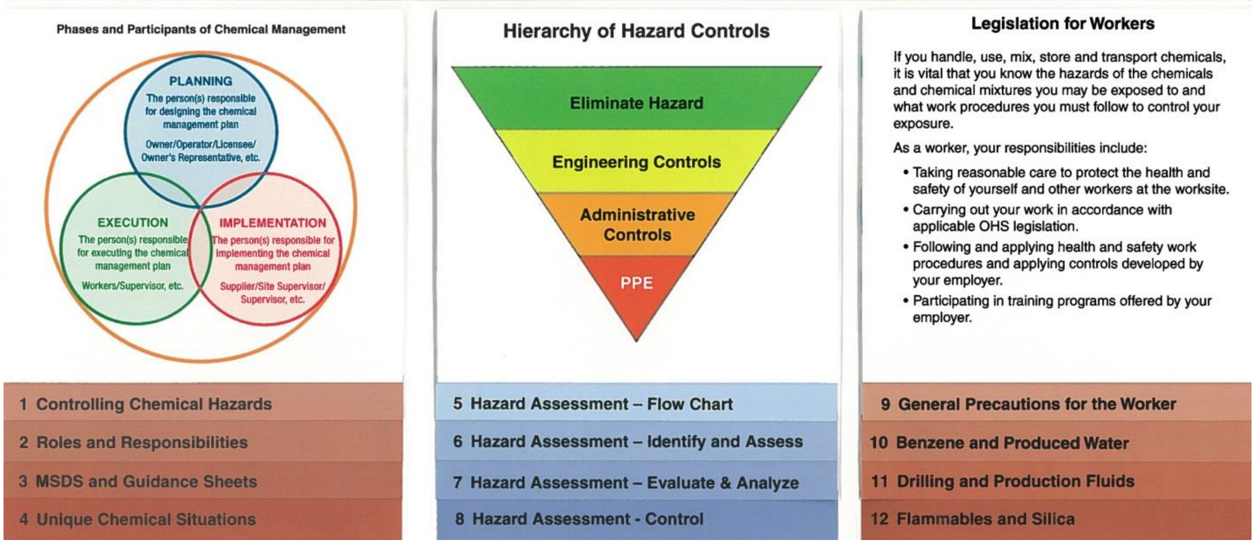
By industry, for industry

CCH Workers' Flip Guide:



Phases and Participants of Chemical Management

PLANNING
The person(s) responsible for designing the chemical management plan
Owner/Operator/Licensee/ Owner's Representative, etc.

EXECUTION
The person(s) responsible for executing the chemical management plan
Workers/Supervisor, etc.

IMPLEMENTATION
The person(s) responsible for implementing the chemical management plan
Supplier/Site Supervisor/ Supervisor, etc.

Hierarchy of Hazard Controls

Eliminate Hazard
Engineering Controls
Administrative Controls
PPE

Legislation for Workers

If you handle, use, mix, store and transport chemicals, it is vital that you know the hazards of the chemicals and chemical mixtures you may be exposed to and what work procedures you must follow to control your exposure.

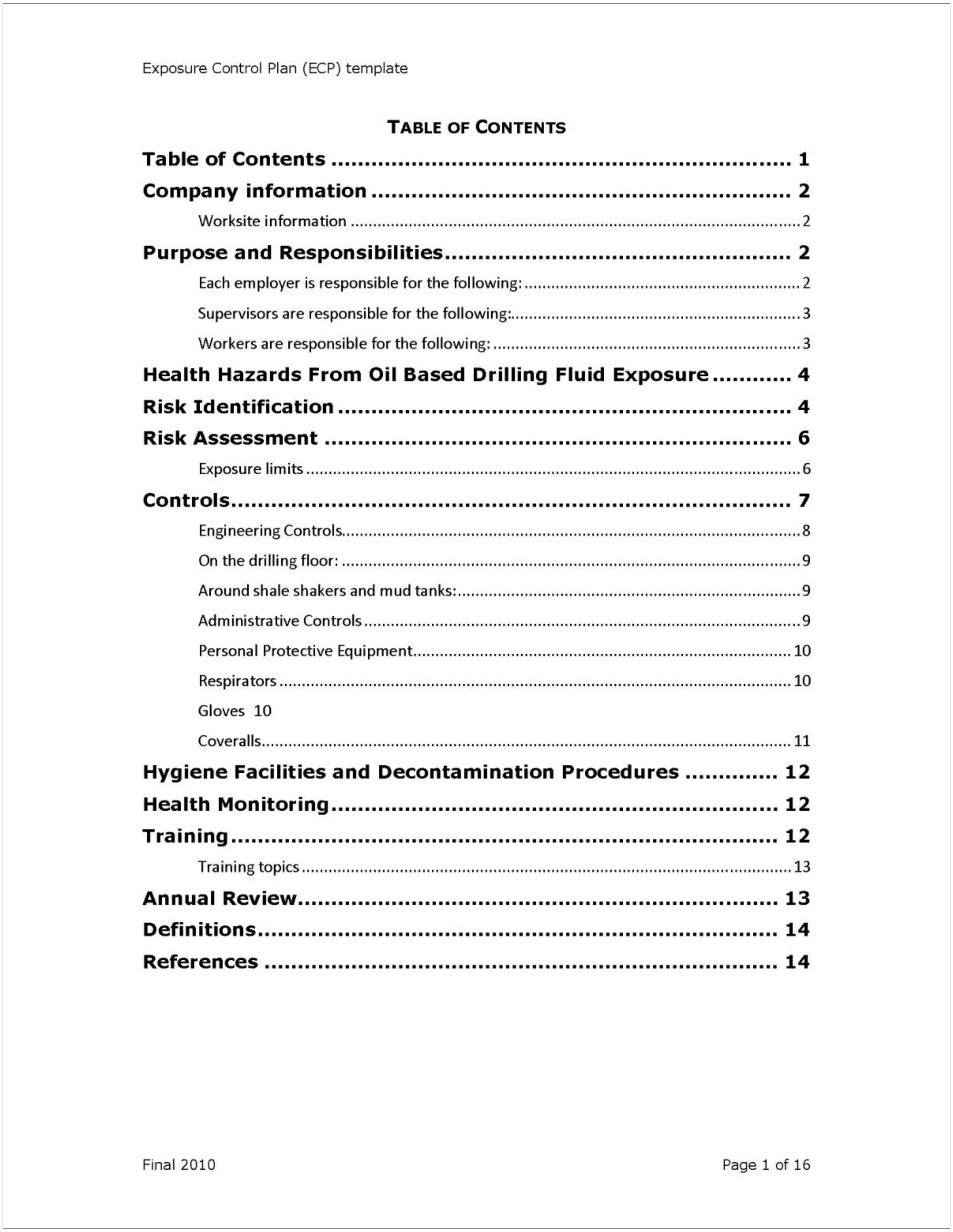
As a worker, your responsibilities include:

- Taking reasonable care to protect the health and safety of yourself and other workers at the worksite.
- Carrying out your work in accordance with applicable OHS legislation.
- Following and applying health and safety work procedures and applying controls developed by your employer.
- Participating in training programs offered by your employer.

1 Controlling Chemical Hazards
2 Roles and Responsibilities
3 MSDS and Guidance Sheets
4 Unique Chemical Situations
5 Hazard Assessment – Flow Chart
6 Hazard Assessment – Identify and Assess
7 Hazard Assessment – Evaluate & Analyze
8 Hazard Assessment - Control
9 General Precautions for the Worker
10 Benzene and Produced Water
11 Drilling and Production Fluids
12 Flammables and Silica

Appendix B: Exposure Control Plan (ECP) Template

An MS-Word version of the most recent edition of the Enform Exposure Control Plan (ECP) Template for editing purposes is available at www.enform.ca.



Exposure Control Plan (ECP) template

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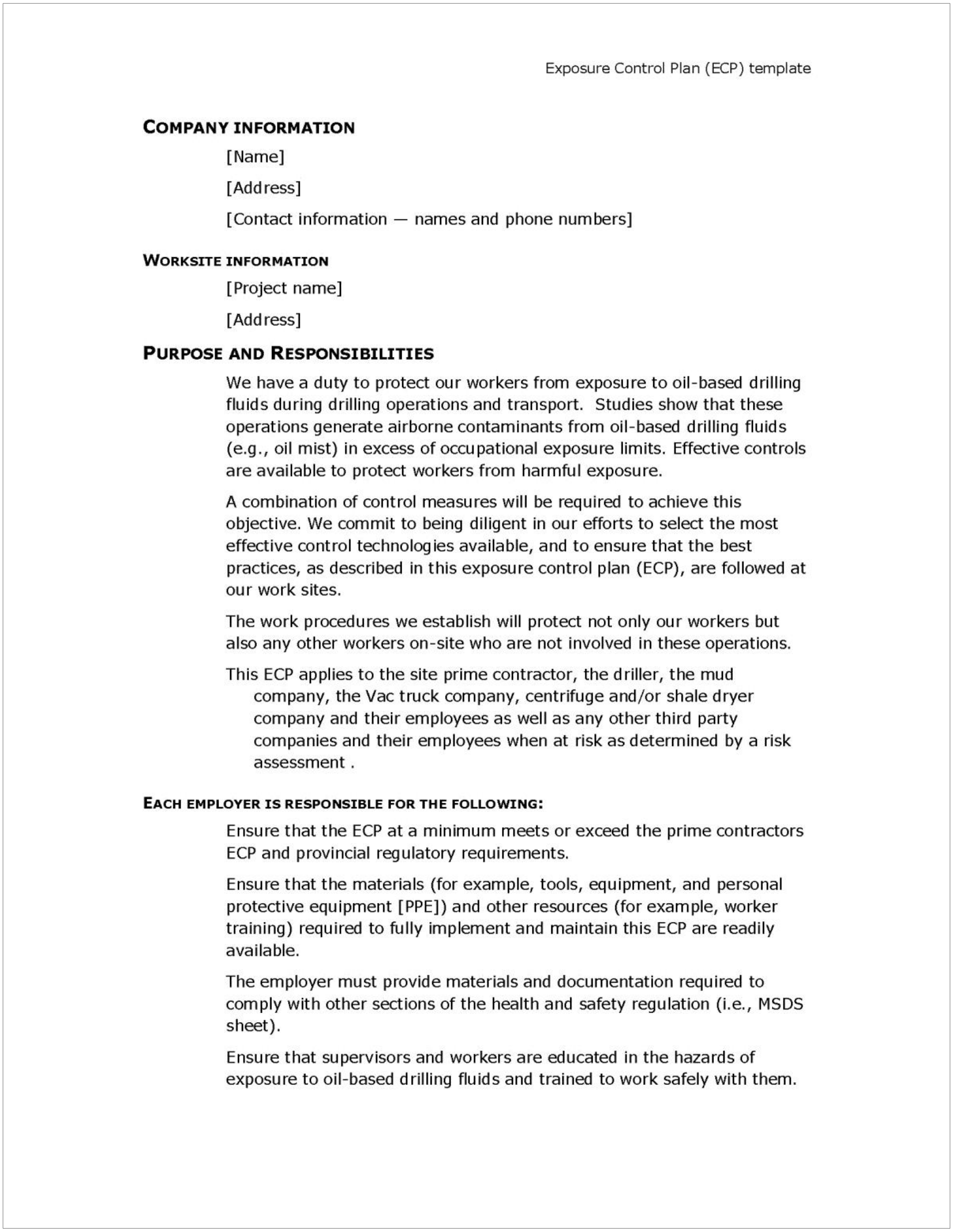


Exposure Control Plan (ECP) template

COMPANY INFORMATION

[Name]

[Address]

[Contact information — names and phone numbers]

WORKSITE INFORMATION

[Project name]

[Address]

PURPOSE AND RESPONSIBILITIES

We have a duty to protect our workers from exposure to oil-based drilling fluids during drilling operations and transport. Studies show that these operations generate airborne contaminants from oil-based drilling fluids (e.g., oil mist) in excess of occupational exposure limits. Effective controls are available to protect workers from harmful exposure.

A combination of control measures will be required to achieve this objective. We commit to being diligent in our efforts to select the most effective control technologies available, and to ensure that the best practices, as described in this exposure control plan (ECP), are followed at our work sites.

The work procedures we establish will protect not only our workers but also any other workers on-site who are not involved in these operations.

This ECP applies to the site prime contractor, the driller, the mud company, the Vac truck company, centrifuge and/or shale dryer company and their employees as well as any other third party companies and their employees when at risk as determined by a risk assessment .

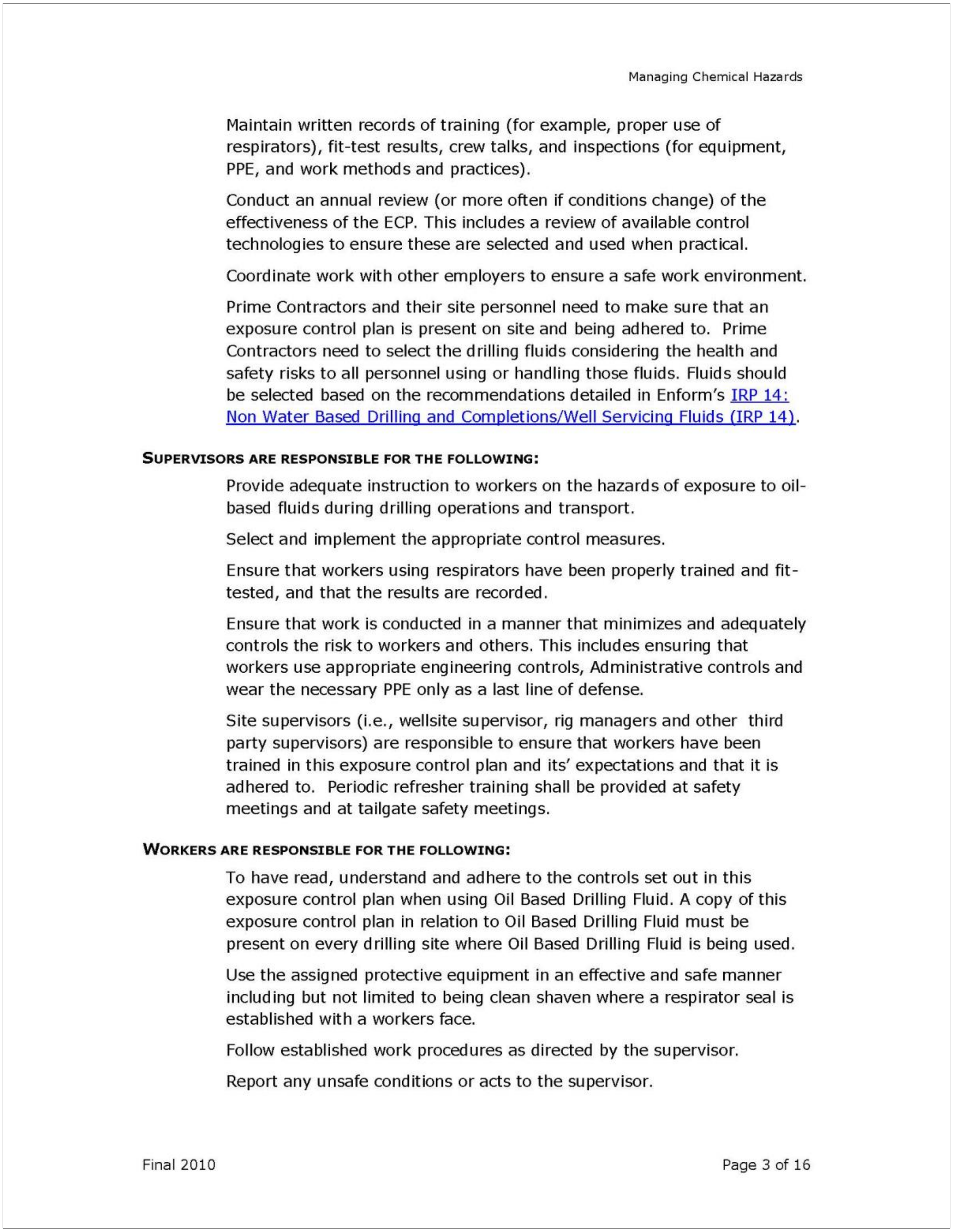
EACH EMPLOYER IS RESPONSIBLE FOR THE FOLLOWING:

Ensure that the ECP at a minimum meets or exceed the prime contractors ECP and provincial regulatory requirements.

Ensure that the materials (for example, tools, equipment, and personal protective equipment [PPE]) and other resources (for example, worker training) required to fully implement and maintain this ECP are readily available.

The employer must provide materials and documentation required to comply with other sections of the health and safety regulation (i.e., MSDS sheet).

Ensure that supervisors and workers are educated in the hazards of exposure to oil-based drilling fluids and trained to work safely with them.



Maintain written records of training (for example, proper use of respirators), fit-test results, crew talks, and inspections (for equipment, PPE, and work methods and practices).

Conduct an annual review (or more often if conditions change) of the effectiveness of the ECP. This includes a review of available control technologies to ensure these are selected and used when practical.

Coordinate work with other employers to ensure a safe work environment.

Prime Contractors and their site personnel need to make sure that an exposure control plan is present on site and being adhered to. Prime Contractors need to select the drilling fluids considering the health and safety risks to all personnel using or handling those fluids. Fluids should be selected based on the recommendations detailed in Enform's IRP 14: Non Water Based Drilling and Completions/Well Servicing Fluids (IRP 14).

SUPERVISORS ARE RESPONSIBLE FOR THE FOLLOWING:

Provide adequate instruction to workers on the hazards of exposure to oil-based fluids during drilling operations and transport.

Select and implement the appropriate control measures.

Ensure that workers using respirators have been properly trained and fit-tested, and that the results are recorded.

Ensure that work is conducted in a manner that minimizes and adequately controls the risk to workers and others. This includes ensuring that workers use appropriate engineering controls, Administrative controls and wear the necessary PPE only as a last line of defense.

Site supervisors (i.e., wellsite supervisor, rig managers and other third party supervisors) are responsible to ensure that workers have been trained in this exposure control plan and its' expectations and that it is adhered to. Periodic refresher training shall be provided at safety meetings and at tailgate safety meetings.

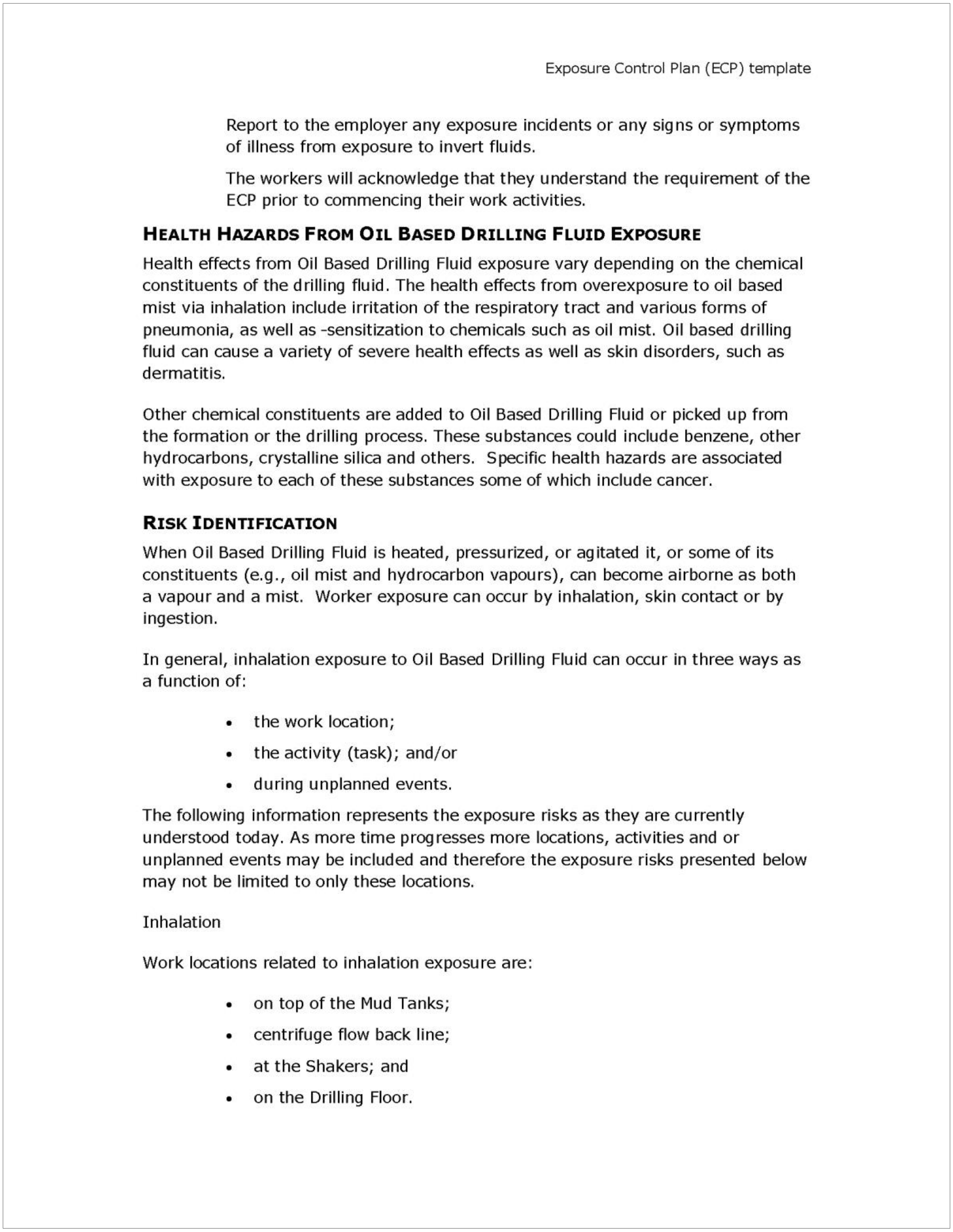
WORKERS ARE RESPONSIBLE FOR THE FOLLOWING:

To have read, understand and adhere to the controls set out in this exposure control plan when using Oil Based Drilling Fluid. A copy of this exposure control plan in relation to Oil Based Drilling Fluid must be present on every drilling site where Oil Based Drilling Fluid is being used.

Use the assigned protective equipment in an effective and safe manner including but not limited to being clean shaven where a respirator seal is established with a workers face.

Follow established work procedures as directed by the supervisor.

Report any unsafe conditions or acts to the supervisor.



Report to the employer any exposure incidents or any signs or symptoms of illness from exposure to invert fluids.

The workers will acknowledge that they understand the requirement of the ECP prior to commencing their work activities.

HEALTH HAZARDS FROM OIL BASED DRILLING FLUID EXPOSURE

Health effects from Oil Based Drilling Fluid exposure vary depending on the chemical constituents of the drilling fluid. The health effects from overexposure to oil based mist via inhalation include irritation of the respiratory tract and various forms of pneumonia, as well as -sensitization to chemicals such as oil mist. Oil based drilling fluid can cause a variety of severe health effects as well as skin disorders, such as dermatitis.

Other chemical constituents are added to Oil Based Drilling Fluid or picked up from the formation or the drilling process. These substances could include benzene, other hydrocarbons, crystalline silica and others. Specific health hazards are associated with exposure to each of these substances some of which include cancer.

RISK IDENTIFICATION

When Oil Based Drilling Fluid is heated, pressurized, or agitated it, or some of its constituents (e.g., oil mist and hydrocarbon vapours), can become airborne as both a vapour and a mist. Worker exposure can occur by inhalation, skin contact or by ingestion.

In general, inhalation exposure to Oil Based Drilling Fluid can occur in three ways as a function of:

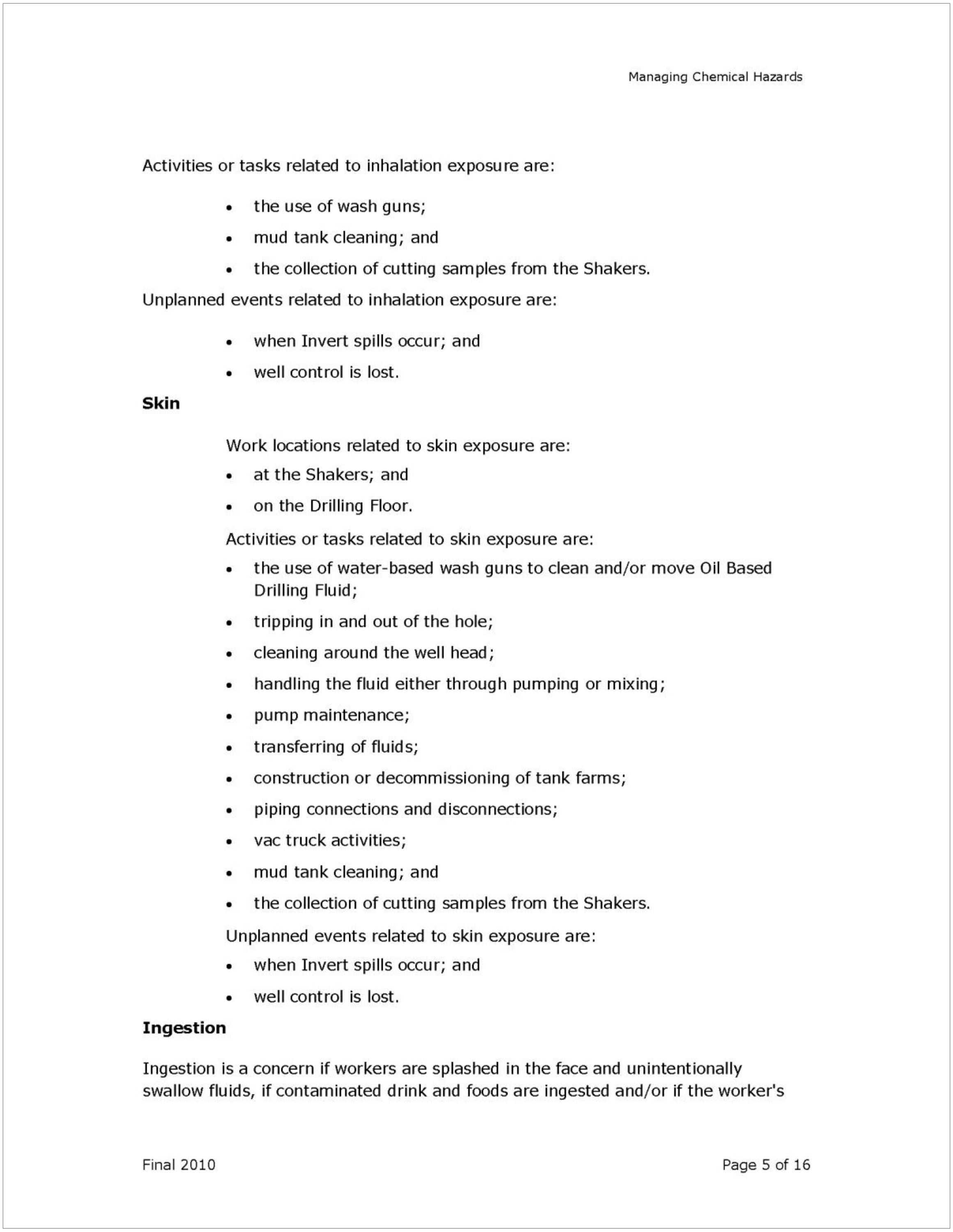
- the work location;
- the activity (task); and/or
- during unplanned events.

The following information represents the exposure risks as they are currently understood today. As more time progresses more locations, activities and or unplanned events may be included and therefore the exposure risks presented below may not be limited to only these locations.

Inhalation

Work locations related to inhalation exposure are:

- on top of the Mud Tanks;
- centrifuge flow back line;
- at the Shakers; and
- on the Drilling Floor.



Activities or tasks related to inhalation exposure are:

- the use of wash guns;
- mud tank cleaning; and
- the collection of cutting samples from the Shakers.

Unplanned events related to inhalation exposure are:

- when Invert spills occur; and
- well control is lost.

Skin

Work locations related to skin exposure are:

- at the Shakers; and
- on the Drilling Floor.

Activities or tasks related to skin exposure are:

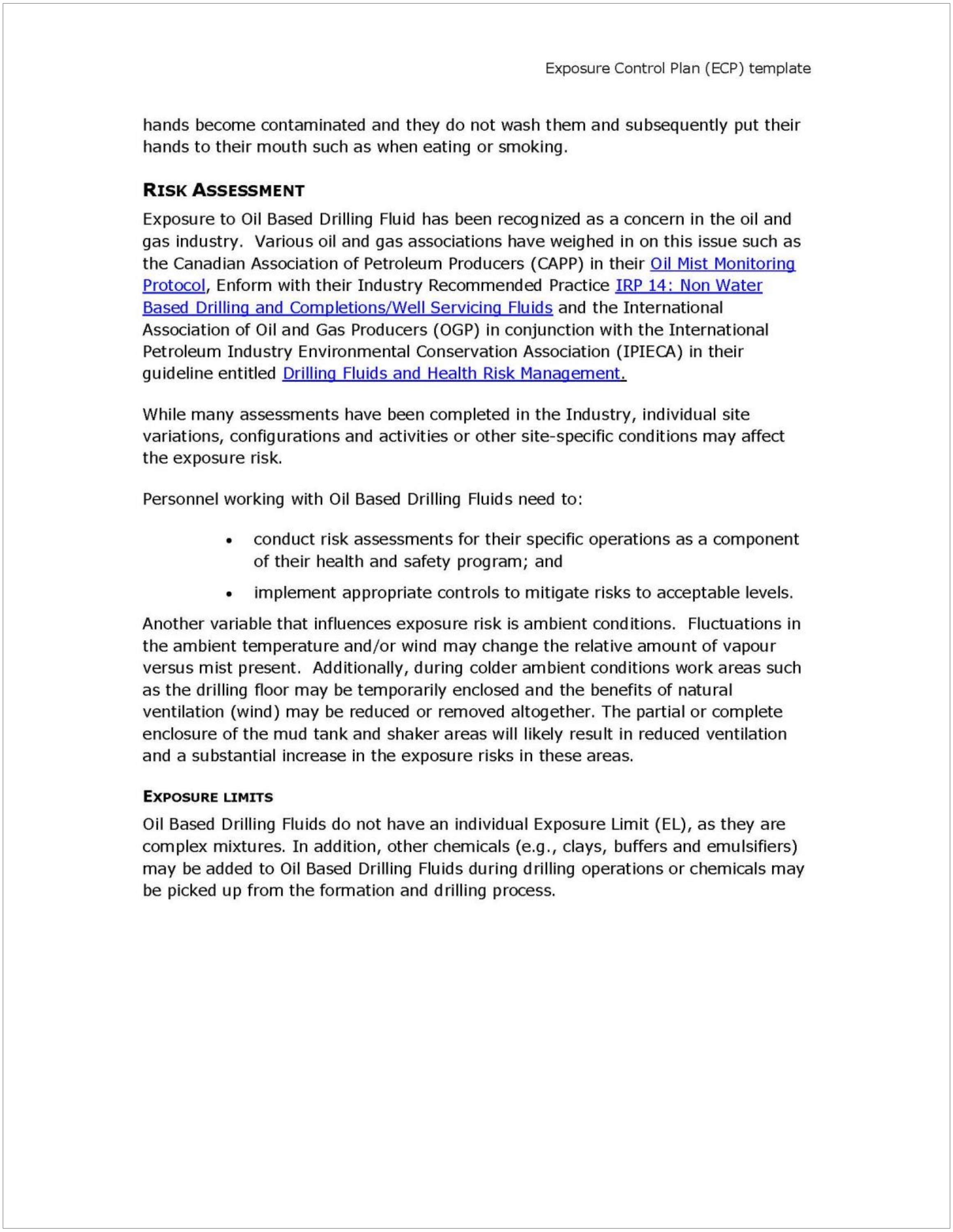
- the use of water-based wash guns to clean and/or move Oil Based Drilling Fluid;
- tripping in and out of the hole;
- cleaning around the well head;
- handling the fluid either through pumping or mixing;
- pump maintenance;
- transferring of fluids;
- construction or decommissioning of tank farms;
- piping connections and disconnections;
- vac truck activities;
- mud tank cleaning; and
- the collection of cutting samples from the Shakers.

Unplanned events related to skin exposure are:

- when Invert spills occur; and
- well control is lost.

Ingestion

Ingestion is a concern if workers are splashed in the face and unintentionally swallow fluids, if contaminated drink and foods are ingested and/or if the worker's



hands become contaminated and they do not wash them and subsequently put their hands to their mouth such as when eating or smoking.

RISK ASSESSMENT

Exposure to Oil Based Drilling Fluid has been recognized as a concern in the oil and gas industry. Various oil and gas associations have weighed in on this issue such as the Canadian Association of Petroleum Producers (CAPP) in their Oil Mist Monitoring Protocol, Enform with their Industry Recommended Practice IRP 14: Non Water Based Drilling and Completions/Well Servicing Fluids and the International Association of Oil and Gas Producers (OGP) in conjunction with the International Petroleum Industry Environmental Conservation Association (IPIECA) in their guideline entitled Drilling Fluids and Health Risk Management.

While many assessments have been completed in the Industry, individual site variations, configurations and activities or other site-specific conditions may affect the exposure risk.

Personnel working with Oil Based Drilling Fluids need to:

- conduct risk assessments for their specific operations as a component of their health and safety program; and
- implement appropriate controls to mitigate risks to acceptable levels.

Another variable that influences exposure risk is ambient conditions. Fluctuations in the ambient temperature and/or wind may change the relative amount of vapour versus mist present. Additionally, during colder ambient conditions work areas such as the drilling floor may be temporarily enclosed and the benefits of natural ventilation (wind) may be reduced or removed altogether. The partial or complete enclosure of the mud tank and shaker areas will likely result in reduced ventilation and a substantial increase in the exposure risks in these areas.

EXPOSURE LIMITS

Oil Based Drilling Fluids do not have an individual Exposure Limit (EL), as they are complex mixtures. In addition, other chemicals (e.g., clays, buffers and emulsifiers) may be added to Oil Based Drilling Fluids during drilling operations or chemicals may be picked up from the formation and drilling process.

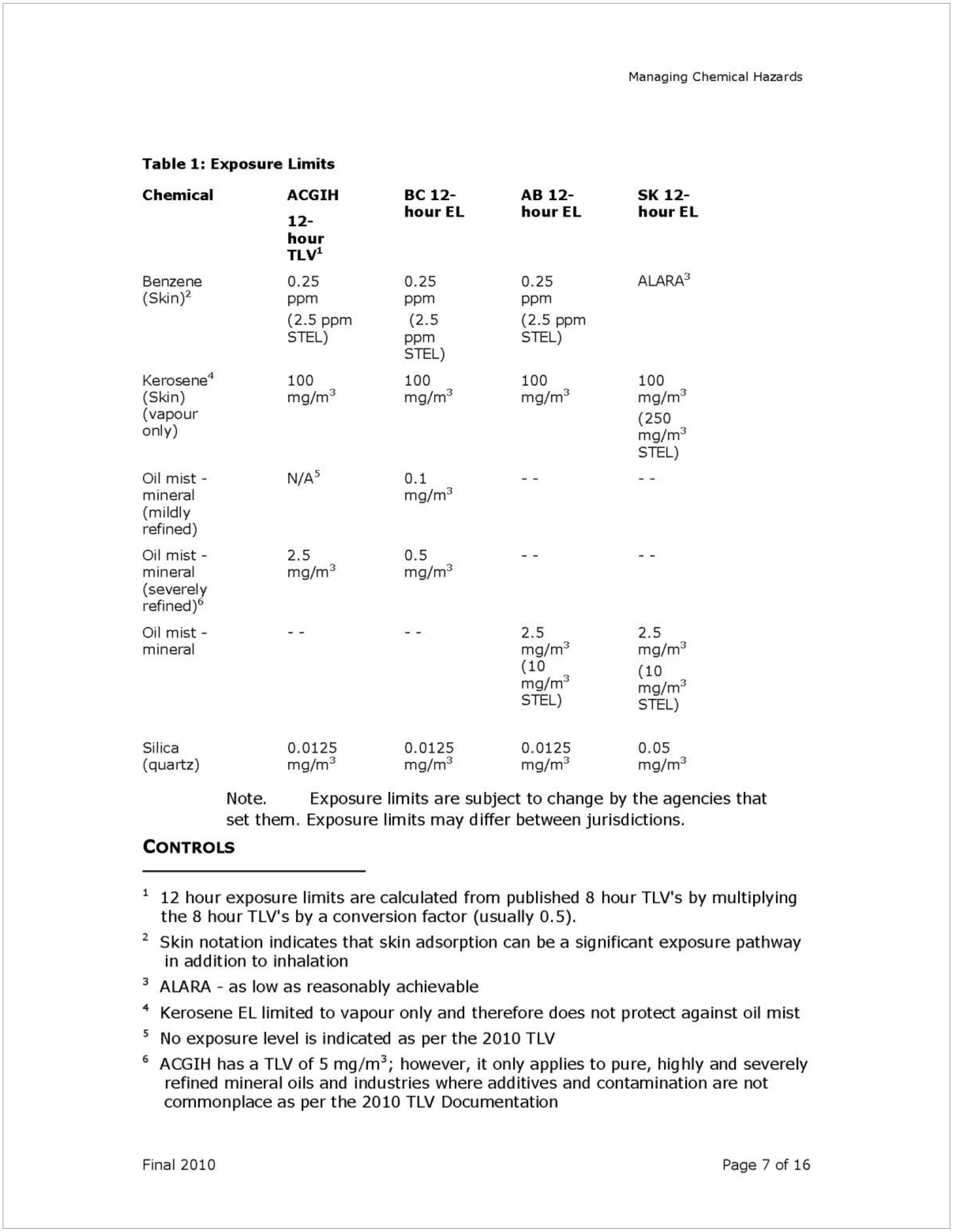


Table 1: Exposure Limits

Chemical	ACGIH 12-hour TLV[1]	BC 12-hour EL	AB 12-hour EL	SK 12-hour EL
Benzene (Skin)[2]	0.25 ppm (2.5 ppm STEL)	0.25 ppm (2.5 ppm STEL)	0.25 ppm (2.5 ppm STEL)	ALARA[3]
Kerosene[4] (Skin) (vapour only)	100 mg/m^3	100 mg/m^3	100 mg/m^3	100 mg/m^3 (250 mg/m^3 STEL)
Oil mist - mineral (mildly refined)	N/A[5]	0.1 mg/m^3	- -	- -
Oil mist - mineral (severely refined)[6]	2.5 mg/m^3	0.5 mg/m^3	- -	- -
Oil mist - mineral	- -	- -	2.5 mg/m^3 (10 mg/m^3 STEL)	2.5 mg/m^3 (10 mg/m^3 STEL)
Silica (quartz)	0.0125 mg/m^3	0.0125 mg/m^3	0.0125 mg/m^3	0.05 mg/m^3

Note. Exposure limits are subject to change by the agencies that set them. Exposure limits may differ between jurisdictions.

CONTROLS

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[1] 12 hour exposure limits are calculated from published 8 hour TLV's by multiplying the 8 hour TLV's by a conversion factor (usually 0.5).

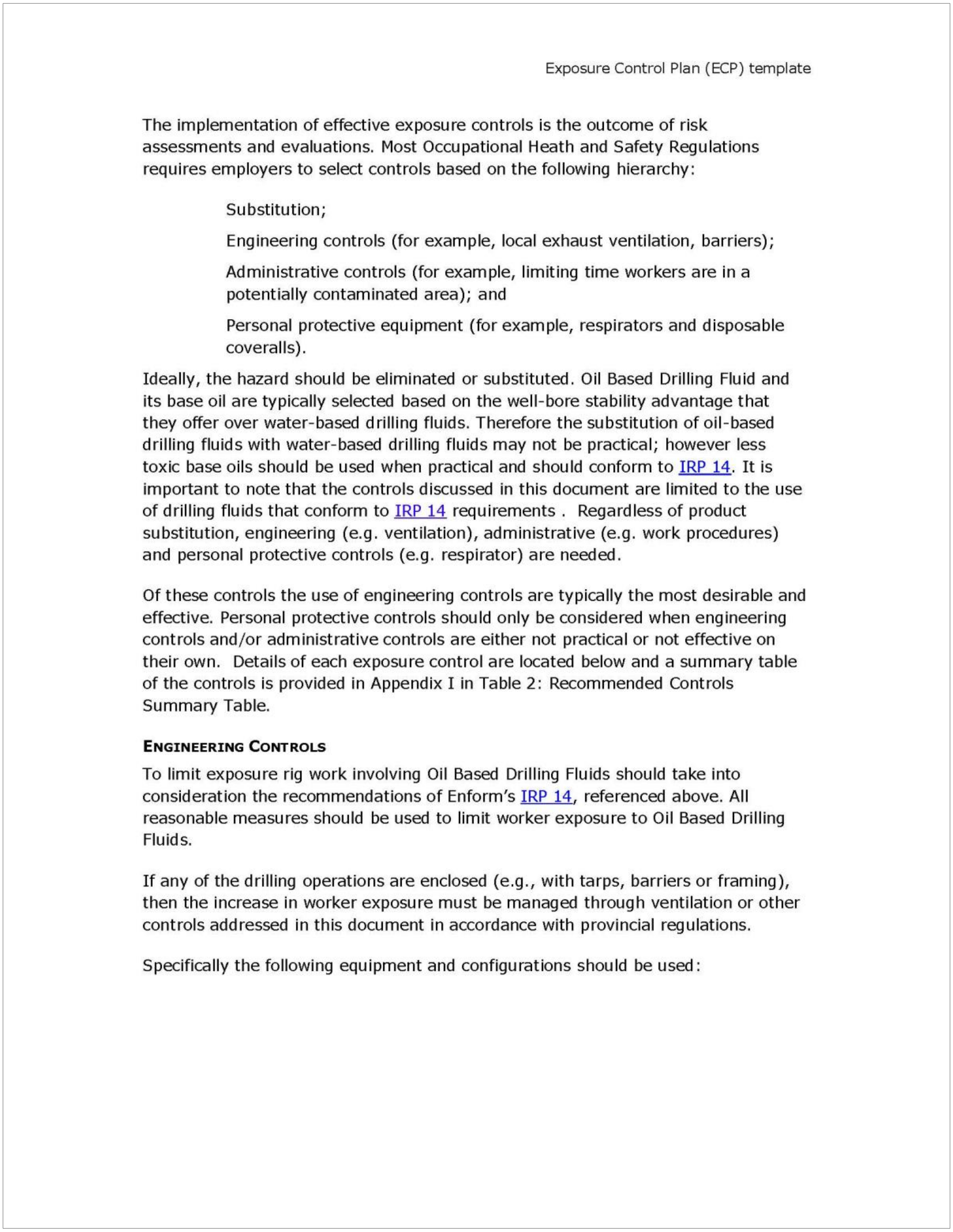
[2] Skin notation indicates that skin adsorption can be a significant exposure pathway in addition to inhalation

[3] ALARA - as low as reasonably achievable

[4] Kerosene EL limited to vapour only and therefore does not protect against oil mist

[5] No exposure level is indicated as per the 2010 TLV

[6] ACGIH has a TLV of 5 mg/m^3; however, it only applies to pure, highly and severely refined mineral oils and industries where additives and contamination are not commonplace as per the 2010 TLV Documentation



Exposure Control Plan (ECP) template

The implementation of effective exposure controls is the outcome of risk assessments and evaluations. Most Occupational Heath and Safety Regulations requires employers to select controls based on the following hierarchy:

Substitution;

Engineering controls (for example, local exhaust ventilation, barriers);

Administrative controls (for example, limiting time workers are in a potentially contaminated area); and

Personal protective equipment (for example, respirators and disposable coveralls).

Ideally, the hazard should be eliminated or substituted. Oil Based Drilling Fluid and its base oil are typically selected based on the well-bore stability advantage that they offer over water-based drilling fluids. Therefore the substitution of oil-based drilling fluids with water-based drilling fluids may not be practical; however less toxic base oils should be used when practical and should conform to IRP 14. It is important to note that the controls discussed in this document are limited to the use of drilling fluids that conform to IRP 14 requirements . Regardless of product substitution, engineering (e.g. ventilation), administrative (e.g. work procedures) and personal protective controls (e.g. respirator) are needed.

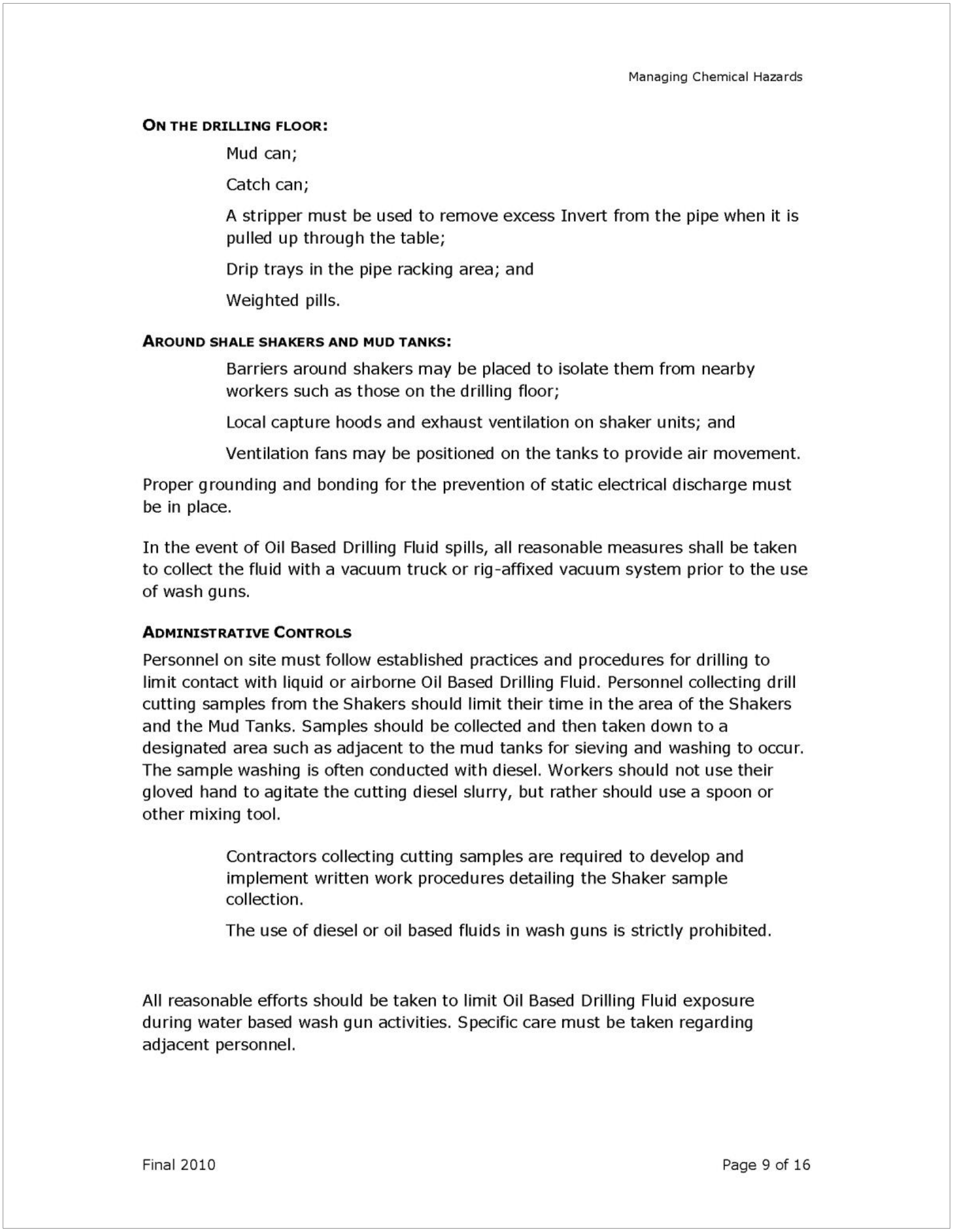
Of these controls the use of engineering controls are typically the most desirable and effective. Personal protective controls should only be considered when engineering controls and/or administrative controls are either not practical or not effective on their own. Details of each exposure control are located below and a summary table of the controls is provided in Appendix I in Table 2: Recommended Controls Summary Table.

ENGINEERING CONTROLS

To limit exposure rig work involving Oil Based Drilling Fluids should take into consideration the recommendations of Enform's IRP 14, referenced above. All reasonable measures should be used to limit worker exposure to Oil Based Drilling Fluids.

If any of the drilling operations are enclosed (e.g., with tarps, barriers or framing), then the increase in worker exposure must be managed through ventilation or other controls addressed in this document in accordance with provincial regulations.

Specifically the following equipment and configurations should be used:



On the drilling floor:

Mud can;

Catch can;

A stripper must be used to remove excess Invert from the pipe when it is pulled up through the table;

Drip trays in the pipe racking area; and

Weighted pills.

Around shale shakers and mud tanks:

Barriers around shakers may be placed to isolate them from nearby workers such as those on the drilling floor;

Local capture hoods and exhaust ventilation on shaker units; and

Ventilation fans may be positioned on the tanks to provide air movement.

Proper grounding and bonding for the prevention of static electrical discharge must be in place.

In the event of Oil Based Drilling Fluid spills, all reasonable measures shall be taken to collect the fluid with a vacuum truck or rig-affixed vacuum system prior to the use of wash guns.

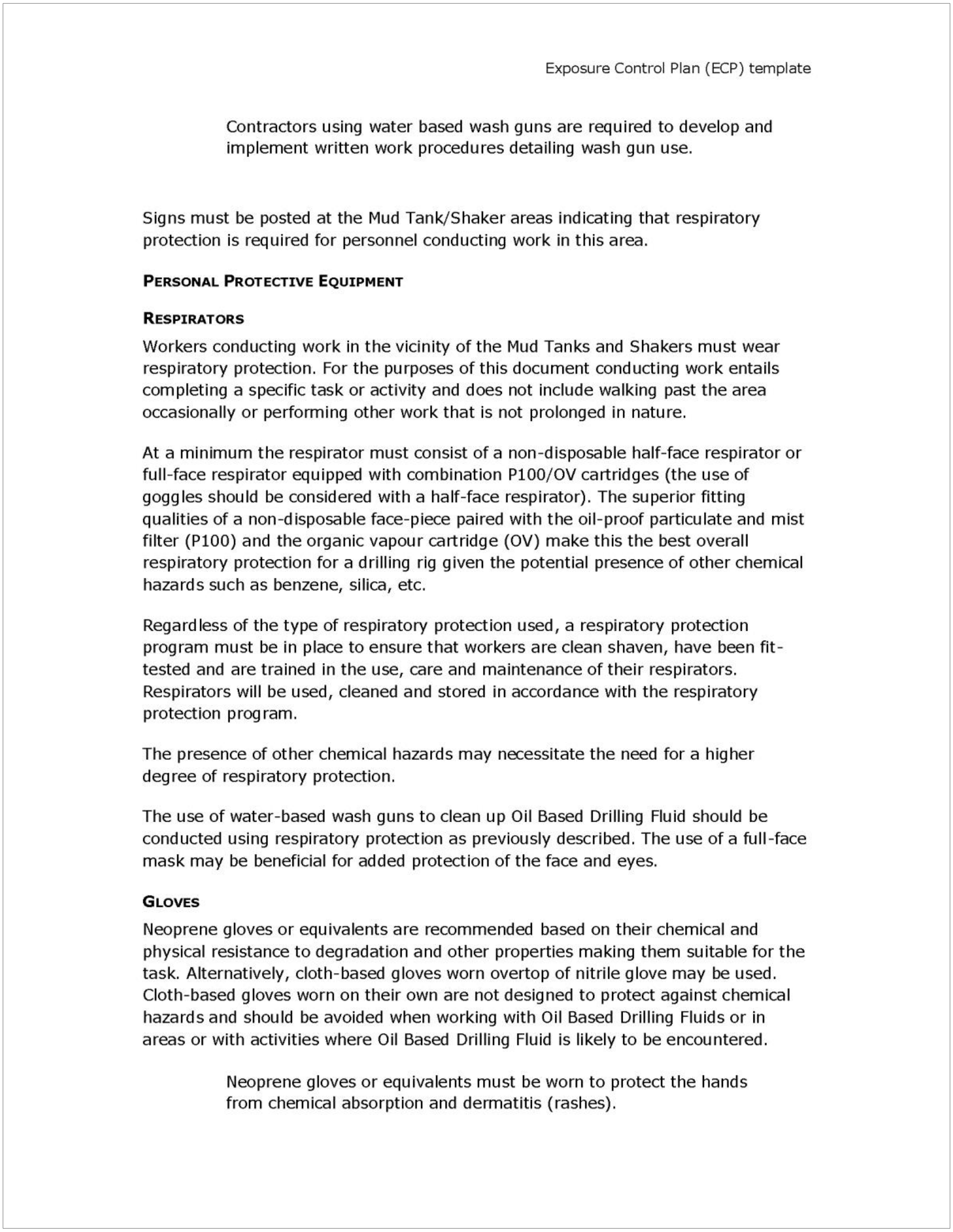
Administrative Controls

Personnel on site must follow established practices and procedures for drilling to limit contact with liquid or airborne Oil Based Drilling Fluid. Personnel collecting drill cutting samples from the Shakers should limit their time in the area of the Shakers and the Mud Tanks. Samples should be collected and then taken down to a designated area such as adjacent to the mud tanks for sieving and washing to occur. The sample washing is often conducted with diesel. Workers should not use their gloved hand to agitate the cutting diesel slurry, but rather should use a spoon or other mixing tool.

Contractors collecting cutting samples are required to develop and implement written work procedures detailing the Shaker sample collection.

The use of diesel or oil based fluids in wash guns is strictly prohibited.

All reasonable efforts should be taken to limit Oil Based Drilling Fluid exposure during water based wash gun activities. Specific care must be taken regarding adjacent personnel.



> Contractors using water based wash guns are required to develop and implement written work procedures detailing wash gun use.

Signs must be posted at the Mud Tank/Shaker areas indicating that respiratory protection is required for personnel conducting work in this area.

PERSONAL PROTECTIVE EQUIPMENT

RESPIRATORS

Workers conducting work in the vicinity of the Mud Tanks and Shakers must wear respiratory protection. For the purposes of this document conducting work entails completing a specific task or activity and does not include walking past the area occasionally or performing other work that is not prolonged in nature.

At a minimum the respirator must consist of a non-disposable half-face respirator or full-face respirator equipped with combination P100/OV cartridges (the use of goggles should be considered with a half-face respirator). The superior fitting qualities of a non-disposable face-piece paired with the oil-proof particulate and mist filter (P100) and the organic vapour cartridge (OV) make this the best overall respiratory protection for a drilling rig given the potential presence of other chemical hazards such as benzene, silica, etc.

Regardless of the type of respiratory protection used, a respiratory protection program must be in place to ensure that workers are clean shaven, have been fit-tested and are trained in the use, care and maintenance of their respirators. Respirators will be used, cleaned and stored in accordance with the respiratory protection program.

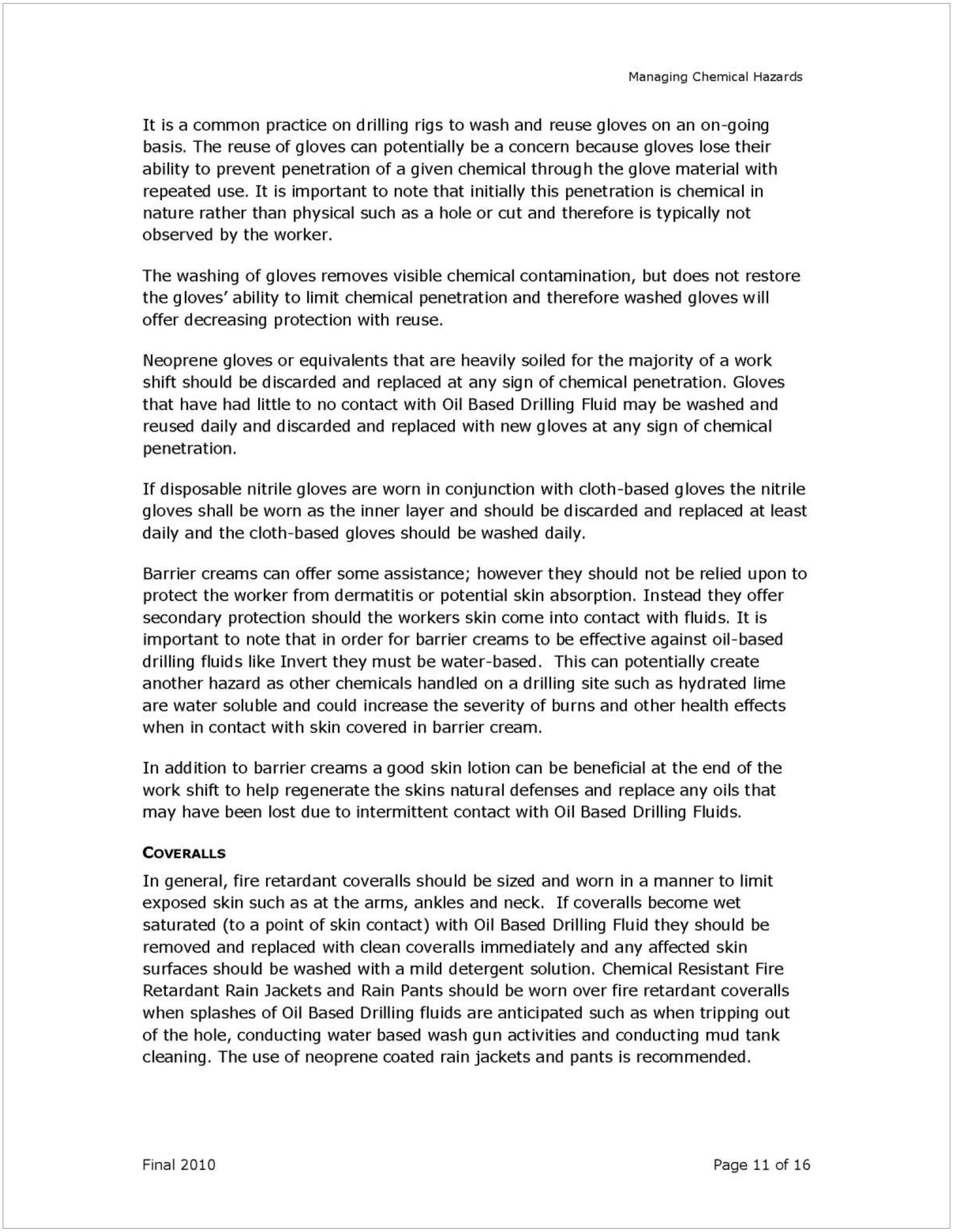
The presence of other chemical hazards may necessitate the need for a higher degree of respiratory protection.

The use of water-based wash guns to clean up Oil Based Drilling Fluid should be conducted using respiratory protection as previously described. The use of a full-face mask may be beneficial for added protection of the face and eyes.

GLOVES

Neoprene gloves or equivalents are recommended based on their chemical and physical resistance to degradation and other properties making them suitable for the task. Alternatively, cloth-based gloves worn overtop of nitrile glove may be used. Cloth-based gloves worn on their own are not designed to protect against chemical hazards and should be avoided when working with Oil Based Drilling Fluids or in areas or with activities where Oil Based Drilling Fluid is likely to be encountered.

> Neoprene gloves or equivalents must be worn to protect the hands from chemical absorption and dermatitis (rashes).



It is a common practice on drilling rigs to wash and reuse gloves on an on-going basis. The reuse of gloves can potentially be a concern because gloves lose their ability to prevent penetration of a given chemical through the glove material with repeated use. It is important to note that initially this penetration is chemical in nature rather than physical such as a hole or cut and therefore is typically not observed by the worker.

The washing of gloves removes visible chemical contamination, but does not restore the gloves' ability to limit chemical penetration and therefore washed gloves will offer decreasing protection with reuse.

Neoprene gloves or equivalents that are heavily soiled for the majority of a work shift should be discarded and replaced at any sign of chemical penetration. Gloves that have had little to no contact with Oil Based Drilling Fluid may be washed and reused daily and discarded and replaced with new gloves at any sign of chemical penetration.

If disposable nitrile gloves are worn in conjunction with cloth-based gloves the nitrile gloves shall be worn as the inner layer and should be discarded and replaced at least daily and the cloth-based gloves should be washed daily.

Barrier creams can offer some assistance; however they should not be relied upon to protect the worker from dermatitis or potential skin absorption. Instead they offer secondary protection should the workers skin come into contact with fluids. It is important to note that in order for barrier creams to be effective against oil-based drilling fluids like Invert they must be water-based. This can potentially create another hazard as other chemicals handled on a drilling site such as hydrated lime are water soluble and could increase the severity of burns and other health effects when in contact with skin covered in barrier cream.

In addition to barrier creams a good skin lotion can be beneficial at the end of the work shift to help regenerate the skins natural defenses and replace any oils that may have been lost due to intermittent contact with Oil Based Drilling Fluids.

COVERALLS

In general, fire retardant coveralls should be sized and worn in a manner to limit exposed skin such as at the arms, ankles and neck. If coveralls become wet saturated (to a point of skin contact) with Oil Based Drilling Fluid they should be removed and replaced with clean coveralls immediately and any affected skin surfaces should be washed with a mild detergent solution. Chemical Resistant Fire Retardant Rain Jackets and Rain Pants should be worn over fire retardant coveralls when splashes of Oil Based Drilling fluids are anticipated such as when tripping out of the hole, conducting water based wash gun activities and conducting mud tank cleaning. The use of neoprene coated rain jackets and pants is recommended.

Replace coveralls immediately when they become wet saturated (to a point of skin contact) with Oil Based Drilling Fluid.

HYGIENE FACILITIES AND DECONTAMINATION PROCEDURES

In order to protect workers, decontamination is an integral component of exposure control. The goal is to remove contamination of skin and personal protective equipment to limit the duration of skin exposure and prevent the potential inadvertent ingestion of contaminants. Inadvertent ingestion may occur during eating, drinking, smoking, or other personal habits such as biting of finger nails etc.

Prior to eating, drinking and in general leaving the rig, workers should thoroughly wash their face and hands with a mild detergent solution. Adequate washing facilities must be provided on site to enable worker decontamination. Eating and drinking is restricted to authorized areas only.

Adequate washing facilities must be provided on site to enable worker decontamination.

HEALTH MONITORING

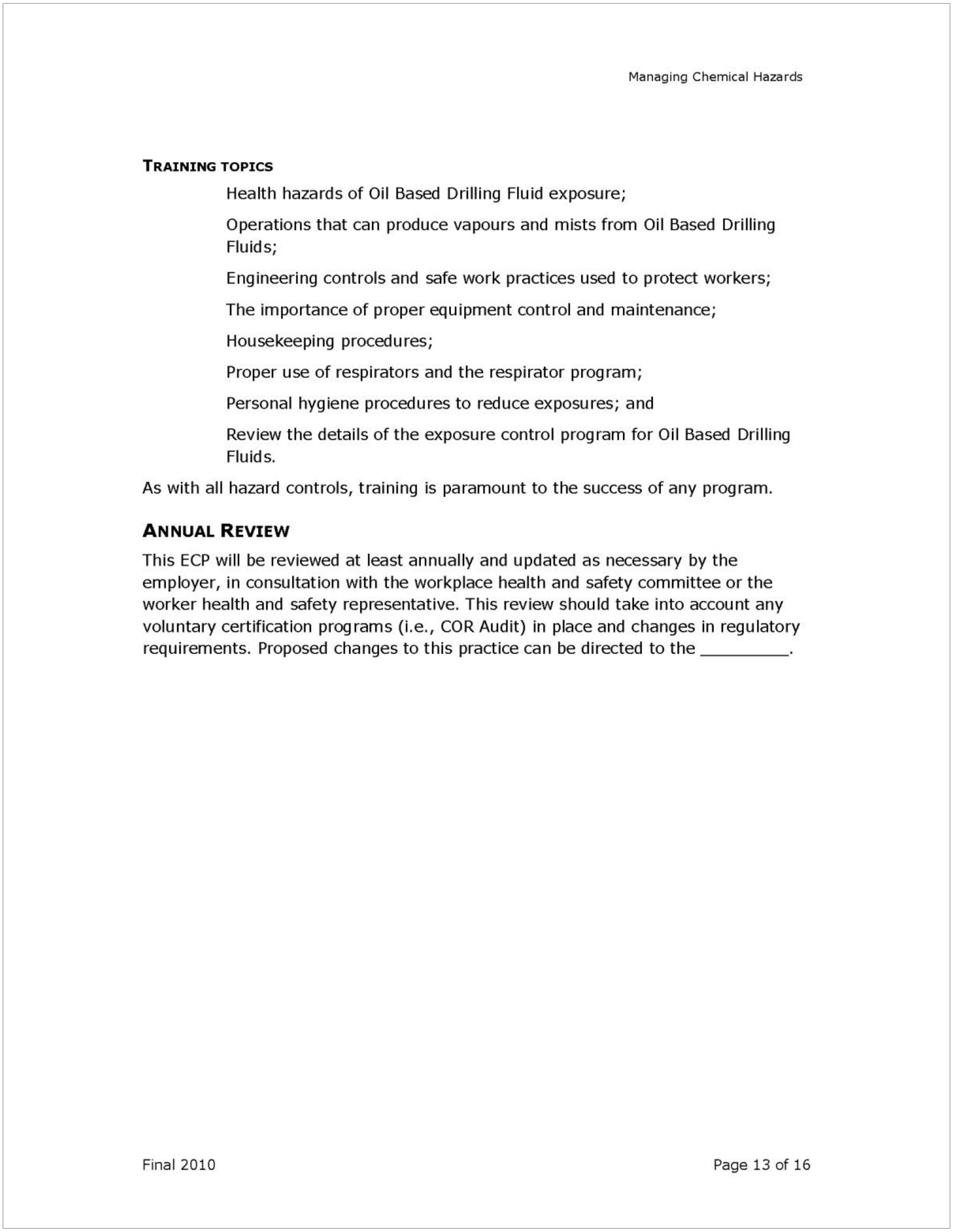
A program of monitoring and evaluating workers health is beneficial, although based on the hazards of Oil Based Drilling Fluid it is not required. However, contractors are expected to address health and wellness issues with their employees such as general fit for work expectations, ability to wear a respirator, and other related components such as respirator fit testing as elements of their health and safety program.

TRAINING

Training will be performed by the employer or the employer's designate.

Records of attendance, dates of training, and training material will be documented and retained.

Additional training or reference material on Oil Base Drilling Fluid exposure will be made available to employees upon request.



TRAINING TOPICS

Health hazards of Oil Based Drilling Fluid exposure;

Operations that can produce vapours and mists from Oil Based Drilling Fluids;

Engineering controls and safe work practices used to protect workers;

The importance of proper equipment control and maintenance;

Housekeeping procedures;

Proper use of respirators and the respirator program;

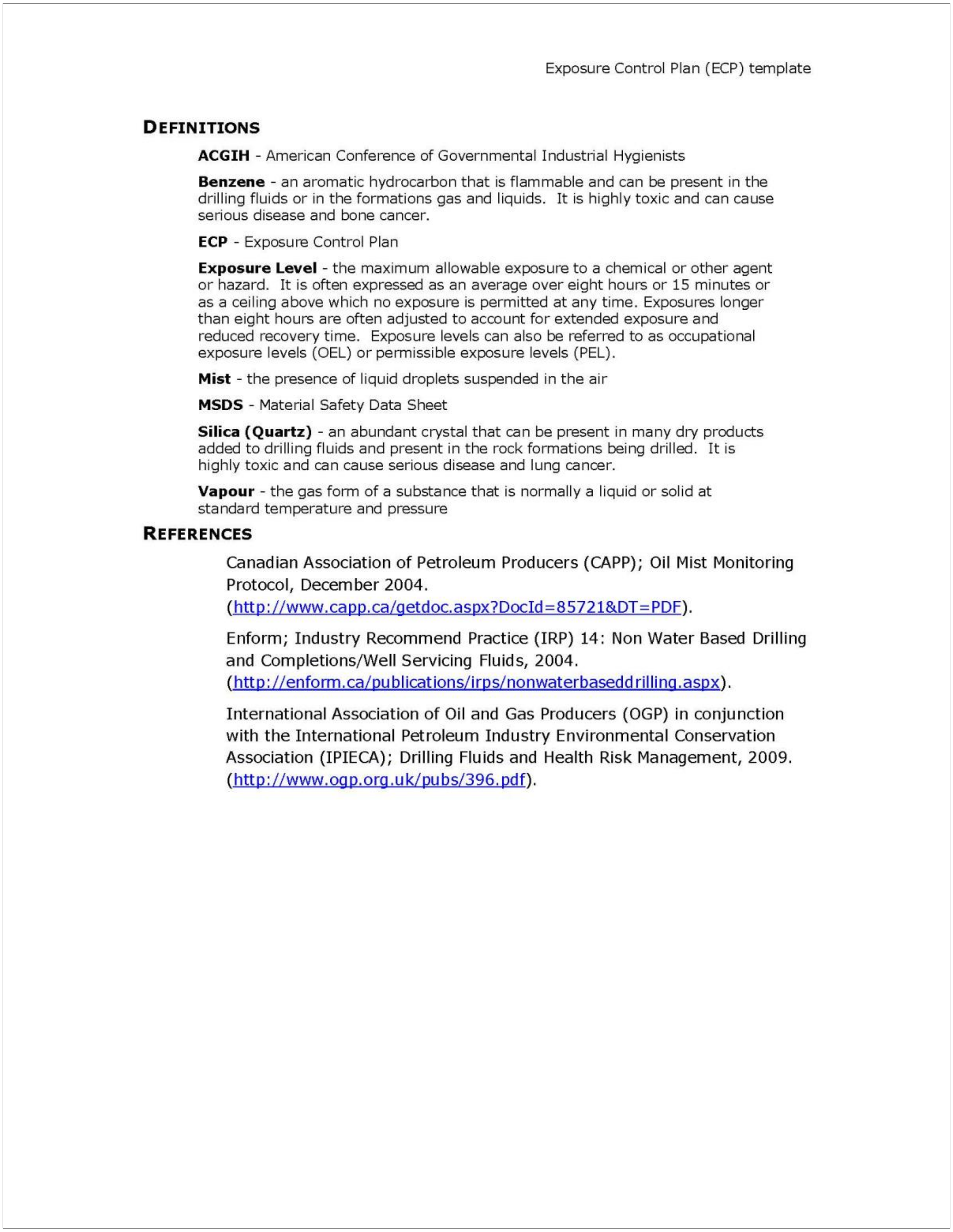
Personal hygiene procedures to reduce exposures; and

Review the details of the exposure control program for Oil Based Drilling Fluids.

As with all hazard controls, training is paramount to the success of any program.

ANNUAL REVIEW

This ECP will be reviewed at least annually and updated as necessary by the employer, in consultation with the workplace health and safety committee or the worker health and safety representative. This review should take into account any voluntary certification programs (i.e., COR Audit) in place and changes in regulatory requirements. Proposed changes to this practice can be directed to the _________.



DEFINITIONS

ACGIH - American Conference of Governmental Industrial Hygienists

Benzene - an aromatic hydrocarbon that is flammable and can be present in the drilling fluids or in the formations gas and liquids. It is highly toxic and can cause serious disease and bone cancer.

ECP - Exposure Control Plan

Exposure Level - the maximum allowable exposure to a chemical or other agent or hazard. It is often expressed as an average over eight hours or 15 minutes or as a ceiling above which no exposure is permitted at any time. Exposures longer than eight hours are often adjusted to account for extended exposure and reduced recovery time. Exposure levels can also be referred to as occupational exposure levels (OEL) or permissible exposure levels (PEL).

Mist - the presence of liquid droplets suspended in the air

MSDS - Material Safety Data Sheet

Silica (Quartz) - an abundant crystal that can be present in many dry products added to drilling fluids and present in the rock formations being drilled. It is highly toxic and can cause serious disease and lung cancer.

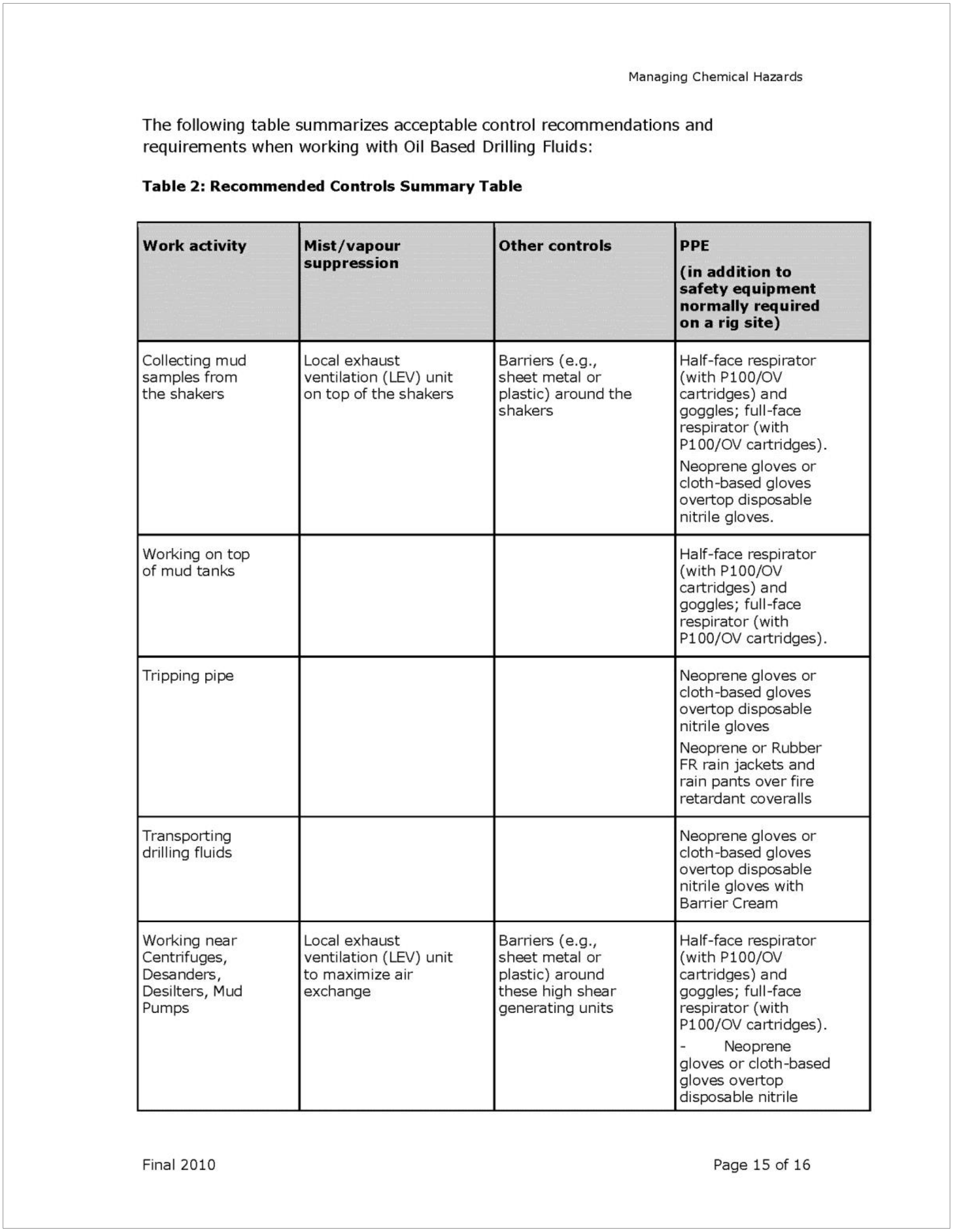
Vapour - the gas form of a substance that is normally a liquid or solid at standard temperature and pressure

REFERENCES

Canadian Association of Petroleum Producers (CAPP); Oil Mist Monitoring Protocol, December 2004. (http://www.capp.ca/getdoc.aspx?DocId=85721&DT=PDF).

Enform; Industry Recommend Practice (IRP) 14: Non Water Based Drilling and Completions/Well Servicing Fluids, 2004. (http://enform.ca/publications/irps/nonwaterbaseddrilling.aspx).

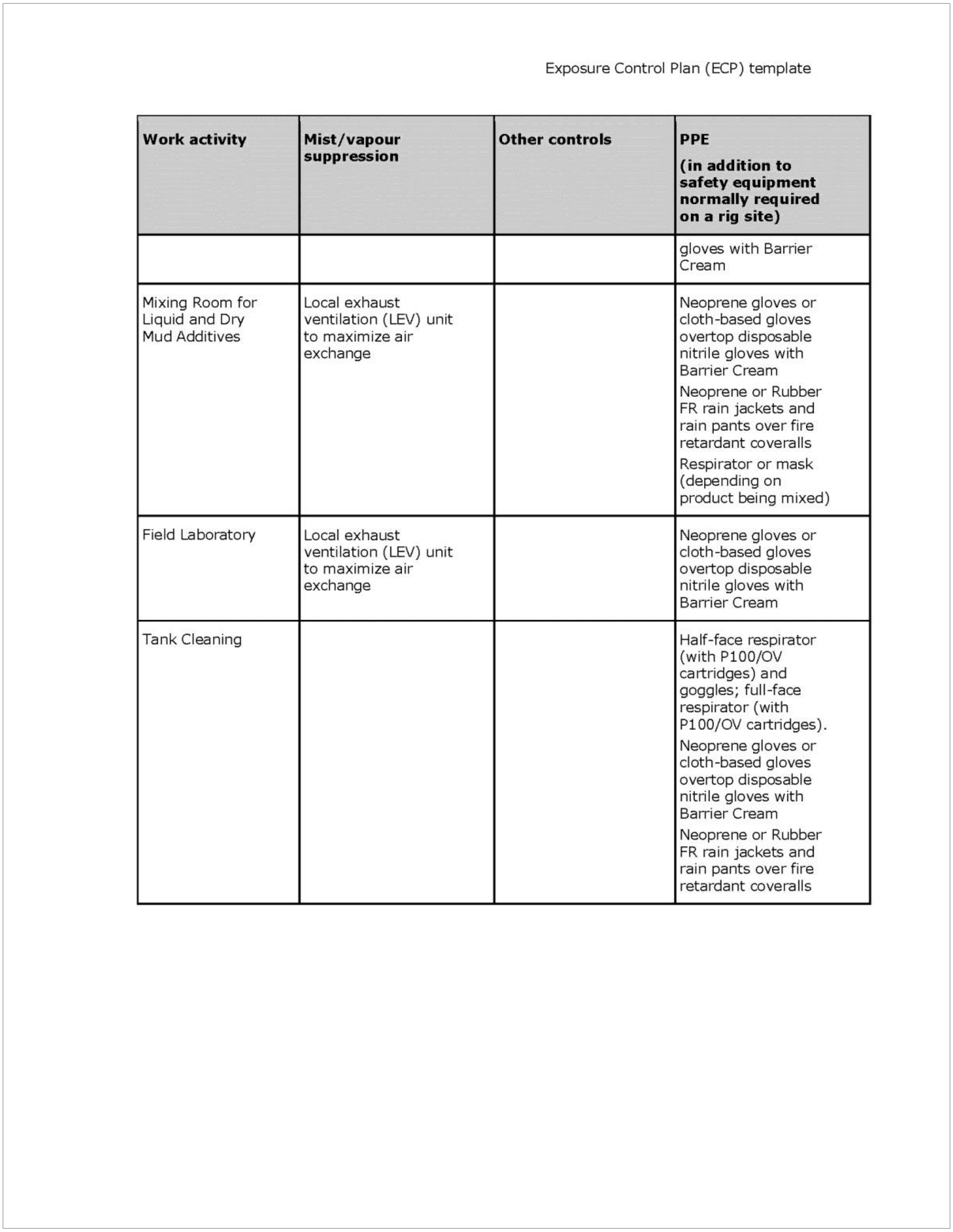
International Association of Oil and Gas Producers (OGP) in conjunction with the International Petroleum Industry Environmental Conservation Association (IPIECA); Drilling Fluids and Health Risk Management, 2009. (http://www.ogp.org.uk/pubs/396.pdf).



The following table summarizes acceptable control recommendations and requirements when working with Oil Based Drilling Fluids:

Table 2: Recommended Controls Summary Table

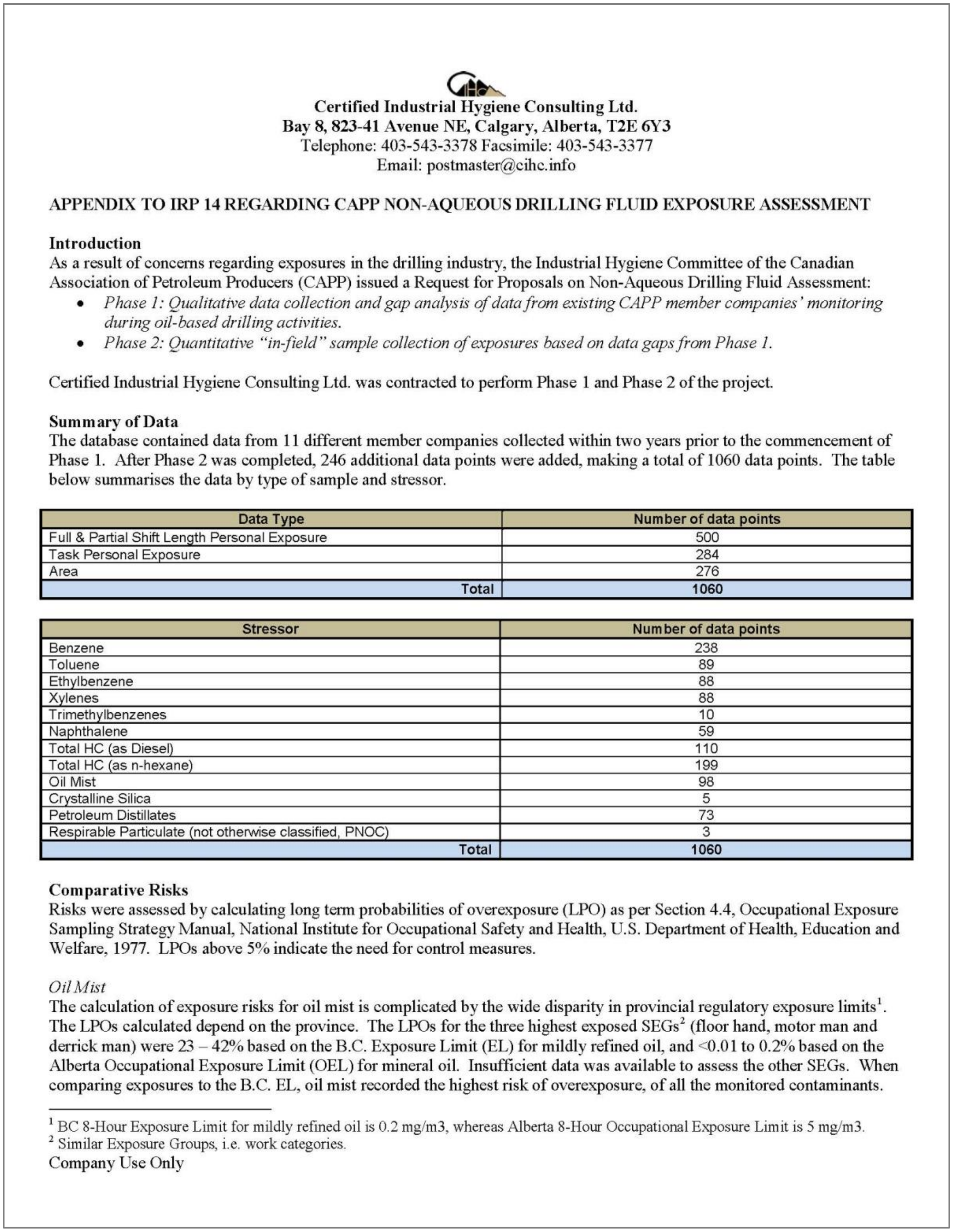
Work activity	**Mist/vapour suppression**	**Other controls**	**PPE (in addition to safety equipment normally required on a rig site)**
Collecting mud samples from the shakers	Local exhaust ventilation (LEV) unit on top of the shakers	Barriers (e.g., sheet metal or plastic) around the shakers	Half-face respirator (with P100/OV cartridges) and goggles; full-face respirator (with P100/OV cartridges). Neoprene gloves or cloth-based gloves overtop disposable nitrile gloves.
Working on top of mud tanks			Half-face respirator (with P100/OV cartridges) and goggles; full-face respirator (with P100/OV cartridges).
Tripping pipe			Neoprene gloves or cloth-based gloves overtop disposable nitrile gloves Neoprene or Rubber FR rain jackets and rain pants over fire retardant coveralls
Transporting drilling fluids			Neoprene gloves or cloth-based gloves overtop disposable nitrile gloves with Barrier Cream
Working near Centrifuges, Desanders, Desilters, Mud Pumps	Local exhaust ventilation (LEV) unit to maximize air exchange	Barriers (e.g., sheet metal or plastic) around these high shear generating units	Half-face respirator (with P100/OV cartridges) and goggles; full-face respirator (with P100/OV cartridges). - Neoprene gloves or cloth-based gloves overtop disposable nitrile



Exposure Control Plan (ECP) template

Work activity	**Mist/vapour suppression**	**Other controls**	**PPE** **(in addition to safety equipment normally required on a rig site)**
			gloves with Barrier Cream
Mixing Room for Liquid and Dry Mud Additives	Local exhaust ventilation (LEV) unit to maximize air exchange		Neoprene gloves or cloth-based gloves overtop disposable nitrile gloves with Barrier Cream Neoprene or Rubber FR rain jackets and rain pants over fire retardant coveralls Respirator or mask (depending on product being mixed)
Field Laboratory	Local exhaust ventilation (LEV) unit to maximize air exchange		Neoprene gloves or cloth-based gloves overtop disposable nitrile gloves with Barrier Cream
Tank Cleaning			Half-face respirator (with P100/OV cartridges) and goggles; full-face respirator (with P100/OV cartridges). Neoprene gloves or cloth-based gloves overtop disposable nitrile gloves with Barrier Cream Neoprene or Rubber FR rain jackets and rain pants over fire retardant coveralls

Appendix C: CAPP Non-Aqueous Drilling Fluid Exposure Assessment



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APPENDIX TO IRP 14 REGARDING CAPP NON-AQUEOUS DRILLING FLUID EXPOSURE ASSESSMENT

Introduction

As a result of concerns regarding exposures in the drilling industry, the Industrial Hygiene Committee of the Canadian Association of Petroleum Producers (CAPP) issued a Request for Proposals on Non-Aqueous Drilling Fluid Assessment:

- *Phase 1: Qualitative data collection and gap analysis of data from existing CAPP member companies' monitoring during oil-based drilling activities.*
- *Phase 2: Quantitative "in-field" sample collection of exposures based on data gaps from Phase 1.*

Certified Industrial Hygiene Consulting Ltd. was contracted to perform Phase 1 and Phase 2 of the project.

Summary of Data

The database contained data from 11 different member companies collected within two years prior to the commencement of Phase 1. After Phase 2 was completed, 246 additional data points were added, making a total of 1060 data points. The table below summarises the data by type of sample and stressor.

Data Type	Number of data points
Full & Partial Shift Length Personal Exposure	500
Task Personal Exposure	284
Area	276
Total	**1060**

Stressor	Number of data points
Benzene	238
Toluene	89
Ethylbenzene	88
Xylenes	88
Trimethylbenzenes	10
Naphthalene	59
Total HC (as Diesel)	110
Total HC (as n-hexane)	199
Oil Mist	98
Crystalline Silica	5
Petroleum Distillates	73
Respirable Particulate (not otherwise classified, PNOC)	3
Total	**1060**

Comparative Risks

Risks were assessed by calculating long term probabilities of overexposure (LPO) as per Section 4.4, Occupational Exposure Sampling Strategy Manual, National Institute for Occupational Safety and Health, U.S. Department of Health, Education and Welfare, 1977. LPOs above 5% indicate the need for control measures.

Oil Mist

The calculation of exposure risks for oil mist is complicated by the wide disparity in provincial regulatory exposure limits[1]. The LPOs calculated depend on the province. The LPOs for the three highest exposed SEGs[2] (floor hand, motor man and derrick man) were 23 – 42% based on the B.C. Exposure Limit (EL) for mildly refined oil, and <0.01 to 0.2% based on the Alberta Occupational Exposure Limit (OEL) for mineral oil. Insufficient data was available to assess the other SEGs. When comparing exposures to the B.C. EL, oil mist recorded the highest risk of overexposure, of all the monitored contaminants.

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[1] BC 8-Hour Exposure Limit for mildly refined oil is 0.2 mg/m3, whereas Alberta 8-Hour Occupational Exposure Limit is 5 mg/m3.

[2] Similar Exposure Groups, i.e. work categories.

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The highest LPOs for area samples (using the B.C. EL) were 24 - 32% at the shakers and above the mud tanks during circulation. LPOs for the Alberta OEL were 1% or less. Insufficient data was available to assess exposure risks at the following locations: cleaning mud tanks, on drill floor, at the shale dryer, and inside the geologist's laboratory.

Diesel and Total Volatile Hydrocarbons (THC)
Most of the personal shift-length diesel and THC data were collected on the floor hand, motor man and derrick man, of which the derrick man demonstrated the highest LPO (3.5%). LPOs for the other two SEGs were very low. While diesel exposure appeared to present the next highest risk after oil mist, it is complicated by the differences in the way "diesel" exposures have been analyzed. Standardization is required in this regard. Total volatile hydrocarbons posed very little risk of overexposure.

Area monitoring for diesel at the shaker/s indicated an LPO of 13% by comparison to the shift-length diesel EL and OEL. The results clearly indicated that prolonged work in this area would cause a high exposure risk.

Benzene and Other Individual Hydrocarbons
The only SEG demonstrating an LPO above 1% for shift-length or partial shift-length exposure to benzene was the mud man. However, this was based on only two samples. Generally the results indicated a low exposure risk for benzene. However, limited data was available for a number of other SEGs: mud man, lease hand, driller, vacuum truck operator, track-hoe operator and geologist. The highest short term (task) LPO for benzene was 1.4% while tripping pipe.

The LPOs for the other individual hydrocarbons monitored - toluene, ethylbenzene, xylenes, trimethylbenzenes, n-hexane and naphthalene - were well below 5%. It is concluded that the risk of overexposure to these hydrocarbons was very low.

Crystalline Silica
Very little data was available. Silica exposures may occur through inhalation of dust during addition of certain dry materials, and inhalation of mist at shakers. Little is known about the toxicology of silica inhaled in invert drilling fluid mist.

Risk factors
The main risk factors affecting hydrocarbon and oil mist exposures are concluded to be as follows: spray-cleaning, working around shakers and on mud tanks, tank cleaning, high drilling fluid temperature, enclosed shaker room, lack of shaker room ventilation, type of base oil/mud and additives, ambient conditions (wind, temperature), and type and depth of the formation.

Workers at Risk
Based on the data obtained, the derrick man, floor hand, motor man and possibly mud man appeared to be at highest risk of overexposure. However, data for some of the SEGs was very limited. More data would allow more accurate risk assessment.

Respiratory Protection and Gloves
Respiratory Protection (RPE) appeared to be worn largely at the discretion of the worker, although in some cases supervisors reminded workers of the need for RPE for specific tasks. The RPE seen at sites was suitable for most applications. Monitoring results indicated that the use of RPE was unnecessary except for protection against oil mist.

Fleece knit gloves were the most common type of glove used on the rigs monitored. They do not protect well against fluids, but only one case was seen where significant skin exposure resulted from their use. Nitrile and PVC gloves[3] were often but not always used for tasks such as: mud checks, dry chemical addition, making pipe connections, cleaning samples, collecting samples and tripping.

Recommendations
1. Perform further shift-length sampling of the mud man, geologist, driller, lease hand and vacuum truck operator for oil mist exposure in B.C. Further shift-length sampling for oil mist on all SEGs is warranted in Alberta. Perform further shift-length sampling of the mud man, motor man, geologist, driller, lease hand and vacuum truck operator for diesel hydrocarbons. Perform further shift-length sampling mud man, lease hand, driller, vacuum truck operator, track-hoe operator and geologist for benzene. No further sampling is recommended for other individual hydrocarbons.

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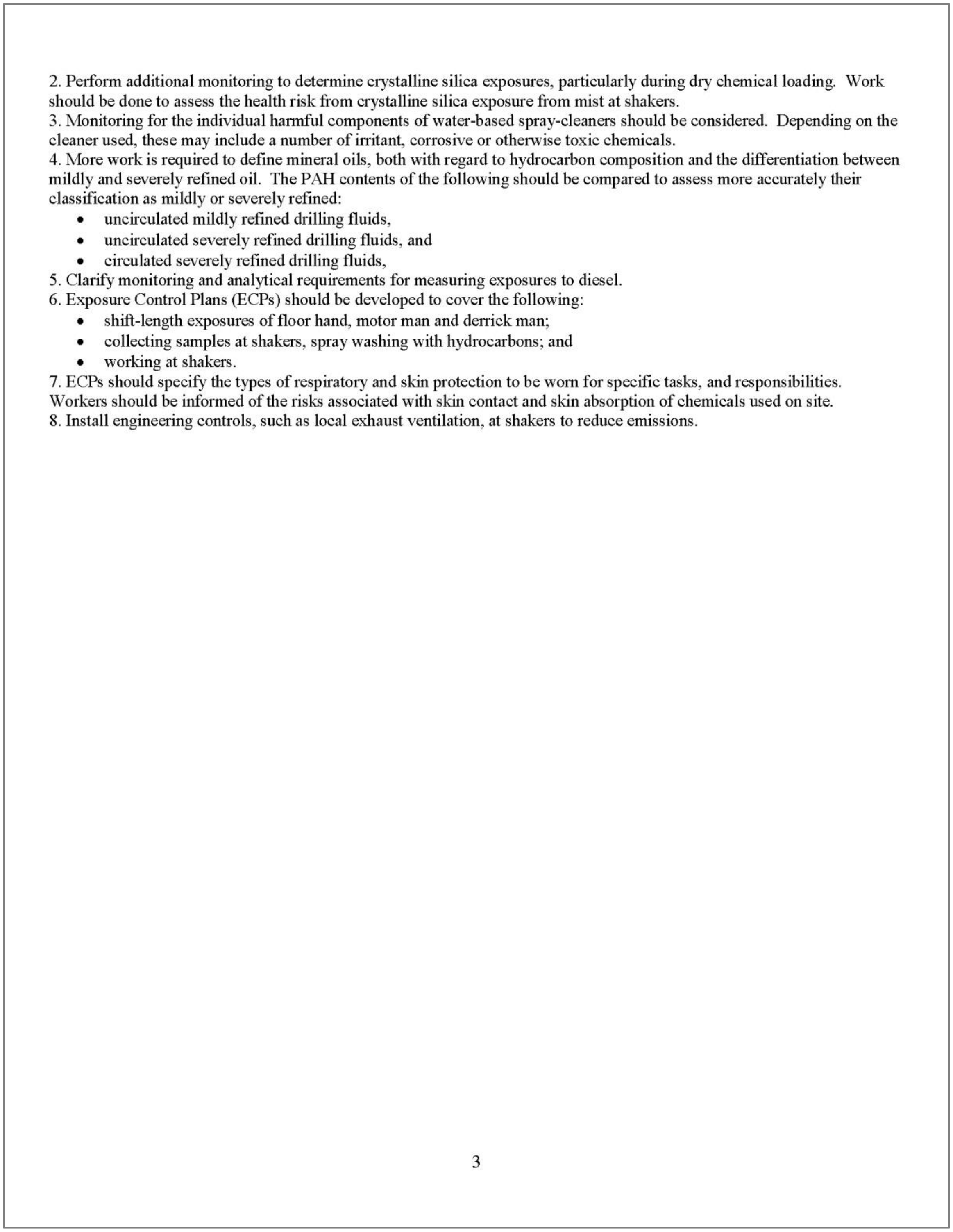
[3] PVC is not as resistant as nitrile to permeation by benzene and other hydrocarbons. Nitrile is generally a better choice for drilling operations.



2. Perform additional monitoring to determine crystalline silica exposures, particularly during dry chemical loading. Work should be done to assess the health risk from crystalline silica exposure from mist at shakers.
3. Monitoring for the individual harmful components of water-based spray-cleaners should be considered. Depending on the cleaner used, these may include a number of irritant, corrosive or otherwise toxic chemicals.
4. More work is required to define mineral oils, both with regard to hydrocarbon composition and the differentiation between mildly and severely refined oil. The PAH contents of the following should be compared to assess more accurately their classification as mildly or severely refined:

- uncirculated mildly refined drilling fluids,
- uncirculated severely refined drilling fluids, and
- circulated severely refined drilling fluids,

5. Clarify monitoring and analytical requirements for measuring exposures to diesel.
6. Exposure Control Plans (ECPs) should be developed to cover the following:

- shift-length exposures of floor hand, motor man and derrick man;
- collecting samples at shakers, spray washing with hydrocarbons; and
- working at shakers.

7. ECPs should specify the types of respiratory and skin protection to be worn for specific tasks, and responsibilities. Workers should be informed of the risks associated with skin contact and skin absorption of chemicals used on site.
8. Install engineering controls, such as local exhaust ventilation, at shakers to reduce emissions.

Appendix D: Characteristics of Non Water Based Drilling Fluid Additives (from IPIECA & OGP *Drilling fluids and health risk management* [Appendix 4])

Physical characteristics of non-aqueous fluids

Primary product function	Type of material	Requirement in NAF	Hazardous classification	Hazardous components	Handling and PPE recommendations
Weighting agent	Barite, ilmenite, hematite, calcium carbonate	Generally barite, almost always	Not classified, dust hazard	May contain SiO_2, respiratory hazard. Mechanical irritation of skin or eyes.	Wear appropriate dust mask/ respirator with filter suitable for the particle size of the dust. Wear safety goggles to protect from mechanical eye irritation. Gloves to protect from mechanical skin irritation.
NAF base fluids (OGP Group III)	Linear paraffins, synthetic iso-alkanes, highly refined mineral oils, olefins	Yes, from 50–95% by volume	Harmful, may cause lung damage if swallowed, some may cause dryness of skin on prolonged or repeated contact	Hydrocarbon aspiration risk if viscosity is <7cSt @ 40 °C. Hydrocarbon may cause skin dryness.	Safety goggles to protect from mist and splashing to the eyes. Organic vapour mask/respirator to protect from inhalation of hydrocarbon mist/vapour. Oil resistant gloves, boots and slicker suits to protect from prolonged skin contact. Effective ventilation systems are essential.
Primary emulsifier (generic)	Hydrophilic and hydrophobic compounds in a carrier fluid - soaps, amines, imidazolines, fatty acid derivatives	Yes, always	May be harmful to skin, eyes, by inhalation or if swallowed. Irritating to skin and eyes. May have aspiration risk, viscosity dependent.	Surfactant fatty acids/ amine derivatives, tall oil reaction products. Hydrocarbon based carrier fluid. Check the MSDS for specific details.	Safety goggles to protect from splashing to the eyes. Organic vapour mask/ respirator if atmosphere heavily contaminated. Chemical/ oil resistant gloves and slicker suits or aprons to protect from prolonged skin contact.
Secondary emulsifier (generic)	Hydrophilic compounds with a positive end in a carrier fluid—polyamides, soaps, amines, imidazolines, fatty acid derivatives	Dependent on NAF type	Irritating to skin and eyes. May have aspiration risk, viscosity dependent.	Surfactant fatty acids/ amine derivatives, tall oil reaction products. Hydrocarbon based carrier fluid. Check the MSDS for specific details.	Safety goggles to protect from splashing to the eyes. Organic vapour mask/ respirator if atmosphere heavily contaminated. Chemical/oil resistant gloves and slicker suits or aprons to protect from prolonged skin contact.
Wetting agent	Hydrophilic compounds primarily—sulphonic acid, amides, polyamides	Dependent on NAF type	Generally irritating to skin and eyes	Surfactant fatty acid derivatives. May contain hydrocarbon carrier fluid. Check the MSDS for specific details.	Safety goggles to protect from splashing to the eyes. Organic vapour mask/ respirator if atmosphere heavily contaminated. Chemical/oil resistant gloves and slicker suits or aprons to protect from prolonged skin contact.
Viscosifiers	Organophillic montmorillonite, attapulgite or hectorite, synthetic polymers—amine treated	Yes, usually montmorillonite	Not classified as hazardous, dust hazard and SiO_2 hazard depending on composition	May contain SiO_2, respiratory hazard, depending on the material. Mechanical irritation to skin/ eyes.	Wear appropriate dust mask/ respirator with filter suitable for the particle size of the dust. Wear safety goggles to protect from mechanical eye irritation. Gloves to protect from mechanical skin irritation.

Physical characteristics of non-aqueous fuids *(continued)*

Primary product function	Type of material	Requirement in NAF	Hazardous classification	Hazardous components	Handling and PPE recommendations
Rheological modifier	Hydrophobic or polymeric compounds, typically fatty acids in liquid products or acrylate co-polymers in powder products	Infrequently, these products tend to be environmentally unacceptable	Not classified as hazardous for liquid products, or for powder products dust hazard only	Fatty acid derivatives may contain hydrocarbon carrier fluid. Check the MSDS for specific details.	Safety goggles to protect from splashing to the eyes. Organic vapour mask/ respirator if atmosphere heavily contaminated. Chemical/oil resistant gloves and slicker suits or aprons to protect from prolonged skin contact.
Brine phase	Fresh water primarily with calcium chloride; see Table 1 for list of alternatives and hazard classifications	Calcium chloride is used in greater than 95% of NAF formulations	Irritating to eyes and skin, prolonged exposure can result in severe skin irritation.	Calcium chloride salt, other salts may be more or less irritating. Check the MSDS for specific details; also see Table 2 in Appendix 6.	Safety goggles and full face shield to protect from splashing, protect from skin/eye irritation. Chemical resistant/impervious gloves, boots and clothing to protect from prolonged exposure
Filtration control	Asphalt, lignite, gilsonite	Not always needed, dependent on mud type and purpose	Not classified, dust hazard	May contain SiO_2, depending on the material. Check the MSDS for specific details.	Wear appropriate dust mask/ respirator with filter suitable for the particle size of the dust. Wear safety goggles to protect from mechanical eye irritation. Gloves to protect from mechanical skin irritation.
Lime	Lime (Calcium hydroxide)	Yes, to activate the emulsifiers in particular	Severe eye irritant, may cause permanent damage. Skin irritant, may be corrosive if skin is moist.	Calcium hydroxide reacts with moisture to be extremely irritating/ corrosive on prolonged contact.	Wear appropriate dust mask/ respirator with filter suitable for fine dust. Wear safety goggles/ face shield to protect from skin/eye irritation. Chemical resistant gloves, boots and clothing to protect from skin irritation and prolonged contact.
Thinners	Liquid products may contain fatty acids. Powder products include lignites, lingo-sulphonate and tannins	Very seldom	Liquid products may be irritating to eyes and skin. Powder products, dust hazard	Liquid products may have a hydrocarbon carrier fluid. Mechancial dust hazard May contain SiO2, depending on the material, check MSDS.	Safety goggles to protect from splashing to the eyes. Organic vapour mask/ respirator if atmosphere heavily contaminated. Chemical/oil resistant gloves and slicker suits or aprons to protect from prolonged skin contact.
Lubricating agent	Ester oils, asphalts, graphite cannot be grouped into one hazard	Seldom, but as deemed necessary	May be a dust hazard for powder products. Ester oils hazards as per NAF base fluids.	Powder products may contain SiO_2.	Powdered products as per weighting agents. Ester—as per NAF Base fluid.
Lost circulation materials	$CaCO_3$, graphite, walnuts shells, mica, almost any solid plugging material available, cross linking pills sometimes resin based	Added only when required, More recent NAF loss prevention procedures can use CaCO3 and graphite maintained in the circulating system	Not classified, dust hazard	May contain SiO_2, depending on the product, check MSDS	Wear appropriate dust mask/ respirator with filter suitable for the particle size of the dust. Wear safety goggles to protect from mechanical eye irritation. Gloves to protect from mechanical skin irritation.

Appendix E: Examples of Common Drilling Fluid Additives (from IPIECA & OGP *Drilling fluids and health risk management* [Appendix 6])

Table 1 below covers both water based (WBM) and non water based (NAF) drilling fluid additives. Table 2 list the types of chemicals used in base brines (the water phase of non water based drilling fluids).

Table 1: Additives common to WBMs and NAFs

Additive	Primary functional potential
Water	
Fresh water	WBM—primary phase; dilution: NAF—internal phase
Sea water	WBM—primary phase; dilution
Brine (see salts)	WBM—primary phase; dilution; formation stability: NAF—internal phase
Saturated NaCl	WBM—primary phase; formation stability
Osmotic—salts	
$CaCl_2$	WBM—primary phase; well control; formation stability: NAF—internal phase
KCl	WBM—primary phase; formation stability
ZnBr/ CaBr	WBM—primary phase; generally a completion fluid
Formates	WBM—primary phase when drilling and for completion operations
Density	
Barite (barium sulphate)	WBM and NAF—fluid density control
Calcium carbonate	WBM and NAF—fluid density control; bridging/plugging agent
Iron carbonate	WBM and NAF—fluid density control
Hematite	WBM and NAF—fluid density control
Ilmenite	WBM and NAF—fluid density control
Viscosity	
Bentonite (or other clays)	WBM—viscosity; fluid loss control
Organophillic clay	NAF—amide modified clay for viscosity control
Biopolymers	WBM—viscosity control; hole cleaning; fluid friction reduction
Carboxymethyl cellulose	WBM—viscosity control; hole cleaning
Polyanionic cellulose	WBM—viscosity control; shale stabilization; hole cleaning: fluid loss control
Guar gum (polysaccharide)	WBM—viscosity
Synthetic polymers	WBM—viscosity often for high temperatures: NAF—viscosity
Dispersants	
Modified polyacrylates	WBM—shale control; fluid loss control
Lignosulphonates	WBM—solids dispersant; limited shale control
Tannins	WBM—solids dispersant
Fluid Loss	
Synthetic polymers	WBM—viscosity often for high temperatures: NAF—viscosity
Carboxymethyl cellulose	WBM—viscosity control; hole cleaning
Polyanionicl cellulose	WBM—viscosity control; shale stabilization; hole cleaning; fluid loss control
Starch	WBM—fluid loss control
Bentonite	WBM—fluid loss control but largely dependent on dispersants
Modified lignites	WBM and NAF—fluid loss control
Asphalt	WBM and NAF—fluid loss control; limited lubricity improvement
Resins	WBM—fluid loss control; limited shale stabilization
Gilsonite	WBM and NAF—fluid loss control; limited lubricity improvement

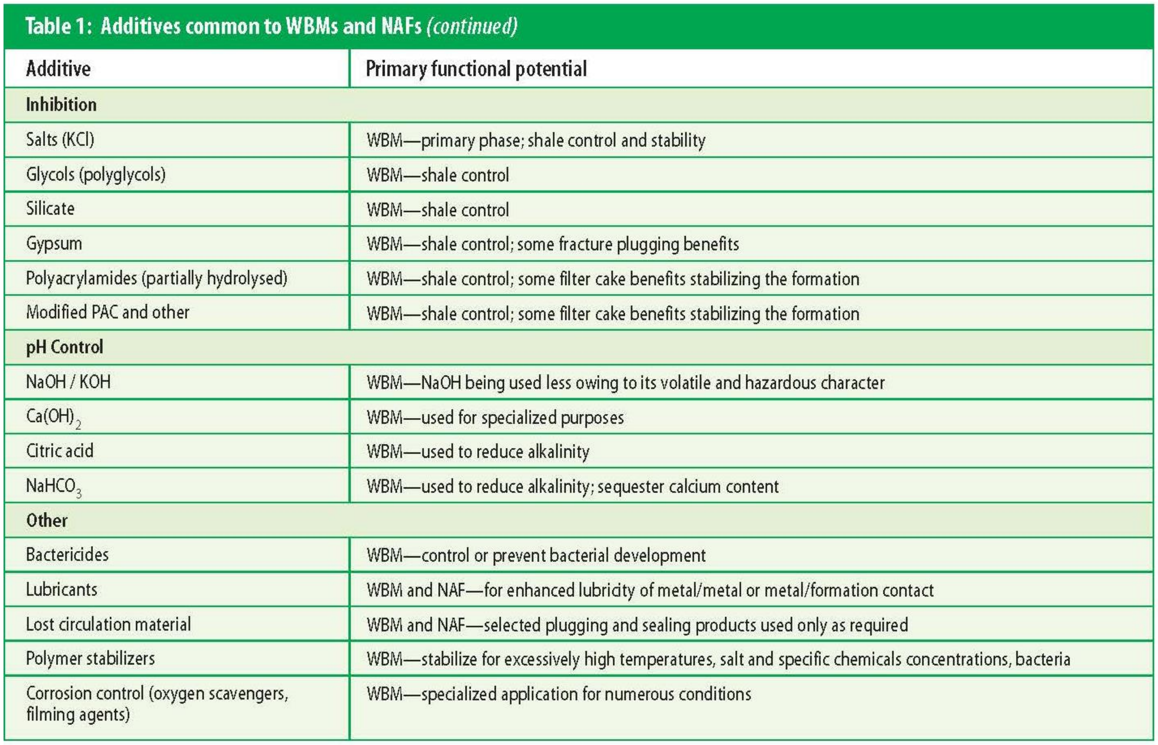


Table 1: Additives common to WBMs and NAFs *(continued)*

Additive	Primary functional potential
Inhibition	
Salts (KCl)	WBM—primary phase; shale control and stability
Glycols (polyglycols)	WBM—shale control
Silicate	WBM—shale control
Gypsum	WBM—shale control; some fracture plugging benefits
Polyacrylamides (partially hydrolysed)	WBM—shale control; some filter cake benefits stabilizing the formation
Modified PAC and other	WBM—shale control; some filter cake benefits stabilizing the formation
pH Control	
NaOH / KOH	WBM—NaOH being used less owing to its volatile and hazardous character
$Ca(OH)_2$	WBM—used for specialized purposes
Citric acid	WBM—used to reduce alkalinity
$NaHCO_3$	WBM—used to reduce alkalinity; sequester calcium content
Other	
Bactericides	WBM—control or prevent bacterial development
Lubricants	WBM and NAF—for enhanced lubricity of metal/metal or metal/formation contact
Lost circulation material	WBM and NAF—selected plugging and sealing products used only as required
Polymer stabilizers	WBM—stabilize for excessively high temperatures, salt and specific chemicals concentrations, bacteria
Corrosion control (oxygen scavengers, filming agents)	WBM—specialized application for numerous conditions

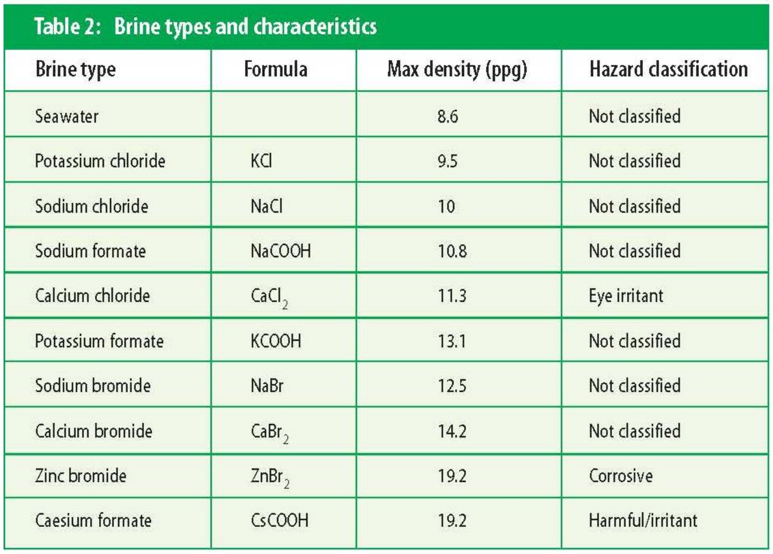
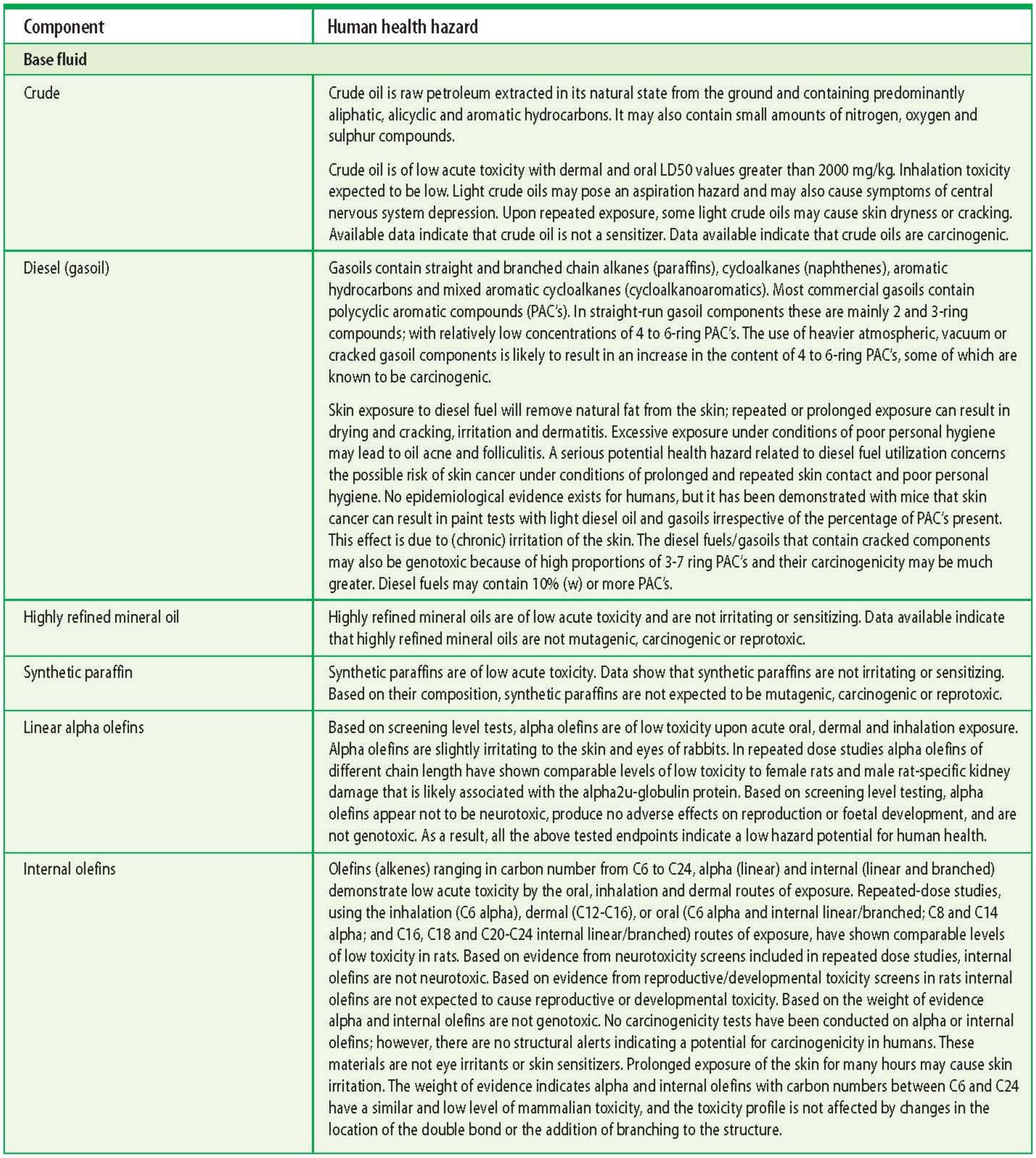


Table 2: Brine types and characteristics

Brine type	Formula	Max density (ppg)	Hazard classification
Seawater		8.6	Not classified
Potassium chloride	KCl	9.5	Not classified
Sodium chloride	NaCl	10	Not classified
Sodium formate	NaCOOH	10.8	Not classified
Calcium chloride	$CaCl_2$	11.3	Eye irritant
Potassium formate	KCOOH	13.1	Not classified
Sodium bromide	NaBr	12.5	Not classified
Calcium bromide	$CaBr_2$	14.2	Not classified
Zinc bromide	$ZnBr_2$	19.2	Corrosive
Caesium formate	CsCOOH	19.2	Harmful/irritant

Appendix F: Detailed Health Hazard Information on Drilling Fluid Components (from IPIECA & OGP *Drilling fluids and health risk management* [Appendix 8])



Component	**Human health hazard**
Base fluid	
Crude	Crude oil is raw petroleum extracted in its natural state from the ground and containing predominantly aliphatic, alicyclic and aromatic hydrocarbons. It may also contain small amounts of nitrogen, oxygen and sulphur compounds. Crude oil is of low acute toxicity with dermal and oral LD50 values greater than 2000 mg/kg. Inhalation toxicity expected to be low. Light crude oils may pose an aspiration hazard and may also cause symptoms of central nervous system depression. Upon repeated exposure, some light crude oils may cause skin dryness or cracking. Available data indicate that crude oil is not a sensitizer. Data available indicate that crude oils are carcinogenic.
Diesel (gasoil)	Gasoils contain straight and branched chain alkanes (paraffins), cycloalkanes (naphthenes), aromatic hydrocarbons and mixed aromatic cycloalkanes (cycloalkanoaromatics). Most commercial gasoils contain polycyclic aromatic compounds (PAC's). In straight-run gasoil components these are mainly 2 and 3-ring compounds; with relatively low concentrations of 4 to 6-ring PAC's. The use of heavier atmospheric, vacuum or cracked gasoil components is likely to result in an increase in the content of 4 to 6-ring PAC's, some of which are known to be carcinogenic. Skin exposure to diesel fuel will remove natural fat from the skin; repeated or prolonged exposure can result in drying and cracking, irritation and dermatitis. Excessive exposure under conditions of poor personal hygiene may lead to oil acne and folliculitis. A serious potential health hazard related to diesel fuel utilization concerns the possible risk of skin cancer under conditions of prolonged and repeated skin contact and poor personal hygiene. No epidemiological evidence exists for humans, but it has been demonstrated with mice that skin cancer can result in paint tests with light diesel oil and gasoils irrespective of the percentage of PAC's present. This effect is due to (chronic) irritation of the skin. The diesel fuels/gasoils that contain cracked components may also be genotoxic because of high proportions of 3-7 ring PAC's and their carcinogenicity may be much greater. Diesel fuels may contain 10% (w) or more PAC's.
Highly refined mineral oil	Highly refined mineral oils are of low acute toxicity and are not irritating or sensitizing. Data available indicate that highly refined mineral oils are not mutagenic, carcinogenic or reprotoxic.
Synthetic paraffin	Synthetic paraffins are of low acute toxicity. Data show that synthetic paraffins are not irritating or sensitizing. Based on their composition, synthetic paraffins are not expected to be mutagenic, carcinogenic or reprotoxic.
Linear alpha olefins	Based on screening level tests, alpha olefins are of low toxicity upon acute oral, dermal and inhalation exposure. Alpha olefins are slightly irritating to the skin and eyes of rabbits. In repeated dose studies alpha olefins of different chain length have shown comparable levels of low toxicity to female rats and male rat-specific kidney damage that is likely associated with the alpha2u-globulin protein. Based on screening level testing, alpha olefins appear not to be neurotoxic, produce no adverse effects on reproduction or foetal development, and are not genotoxic. As a result, all the above tested endpoints indicate a low hazard potential for human health.
Internal olefins	Olefins (alkenes) ranging in carbon number from C6 to C24, alpha (linear) and internal (linear and branched) demonstrate low acute toxicity by the oral, inhalation and dermal routes of exposure. Repeated-dose studies, using the inhalation (C6 alpha), dermal (C12-C16), or oral (C6 alpha and internal linear/branched; C8 and C14 alpha; and C16, C18 and C20-C24 internal linear/branched) routes of exposure, have shown comparable levels of low toxicity in rats. Based on evidence from neurotoxicity screens included in repeated dose studies, internal olefins are not neurotoxic. Based on evidence from reproductive/developmental toxicity screens in rats internal olefins are not expected to cause reproductive or developmental toxicity. Based on the weight of evidence alpha and internal olefins are not genotoxic. No carcinogenicity tests have been conducted on alpha or internal olefins; however, there are no structural alerts indicating a potential for carcinogenicity in humans. These materials are not eye irritants or skin sensitizers. Prolonged exposure of the skin for many hours may cause skin irritation. The weight of evidence indicates alpha and internal olefins with carbon numbers between C6 and C24 have a similar and low level of mammalian toxicity, and the toxicity profile is not affected by changes in the location of the double bond or the addition of branching to the structure.

Component	Human health hazard
Base fluid	
Poly alpha olefin (PAO)	Poly alpha olefins are of low acute toxicity and are not irritating to eye and skin.
Esters	Data on C8-C16 fatty acid 2-ethyl hexanol ester indicate that this ester is of low oral acute toxicity. In an acute skin irritation test in rabbits, minimal skin irritation was observed. The ester is not primarily eye irritant. The ester was non-genotoxic in a micronucleus test. Results from an oral repeated dose study in rats indicate that the ester is not toxic at up to 1000 mg/kg.
Water	
Fresh water	Fresh water is generally considered to be not hazardous to human health.
Sea water	Sea water has a low hazard potential for human health upon inhalation and dermal exposure.
Brine (see salts)	See Table 2 in Appendix 6, and below (osmotic—salts)
Osmotic—salts	
Calcium chloride ($CaCl_2$)	The acute oral and dermal toxicity of calcium chloride is low. The acute oral toxicity is attributed to the severe irritating property of the original substance or its high-concentration solutions to the gastrointestinal tract. In humans, however, acute oral toxicity is rare because large single doses induce nausea and vomiting. Irritation/corrosiveness studies indicate that calcium chloride is not/slightly irritating to skin but severely irritating to eyes of rabbits. Prolonged exposure and application of moistened material or concentrated solutions resulted in considerable skin irritation. The irritating effect of the substance was observed in human skin injuries caused by incidental contact with the substance or its high-concentration solutions. A limited oral repeated dose toxicity study shows no adverse effect of calcium chloride on rats fed on 1000–2000 mg/kg bw/day for 12 months. Calcium and chloride are both essential nutrients for humans and a daily intake of more than 1000 mg each of the ions is recommended. Genetic toxicity of calcium chloride was negative in the bacterial mutation tests and the mammalian chromosome aberration test. No reproductive toxicity study has been reported. A developmental toxicity study reveals no toxic effects on dams or fetuses at doses up to 189 mg/kg bw/day (mice), 176 mg/kg bw/day (rats) and 169 mg/kg bw/day (rabbits). (from: SIDS. *Screening Information Data Set for High Production Volume Chemicals*. (2005)).
Potassium chloride (KCl)	Potassium chloride is an essential constituent of the body for intracellular osmotic pressure and buffering, cell permeability, acid-base balance, muscle contraction and nerve function. Acute oral toxicity of KCl in mammals is low. In humans, acute oral toxicity is rare because large single doses induce nausea and vomiting, and because KCl is rapidly excreted in the absence of any pre-existing kidney damage. The toxicity upon repeated dose exposure is low. A threshold concentration for skin irritancy of 60 % was seen when KCl in aqueous solution was in contact with skin of human volunteers. The threshold concentration when applied to broken skin was 5%. No gene mutations were reported in bacterial tests, with and without metabolic activation. However, high concentrations of KCl showed positive results in a range of genotoxic screening assays using mammalian cells in culture. The action of KCl in culture seems to be an indirect effect associated with an increased osmotic pressure and concentration. No evidence of treatment -related carcinogenicity was observed in rats administered up to 1,820 mg KCl/kg body weight/day through the food in a two-year study. A developmental study revealed no foetotoxic or teratogenic effects of KCl in doses up to 235 mg/kg/day (mice) and 310 mg/kg/day (rats). Gastro-intestinal irritant effects in humans caused by KCl administrated orally have been reported at doses from about 31 mg/kg bw/day. One epidemiological investigation among potash miners disclosed no evidence of predisposition of underground miners to any of the diseases evaluated, including lung cancer. (from: SIDS. *Screening Information Data Set for High Production Volume Chemicals*. (2004)).
Sodium chloride (NaCl)	Sodium chloride is an essential nutrient for the normal functioning of the body. It is important for nerve conduction, muscle contraction, correct osmotic balance of extra cellular fluid and the absorption of other nutrients. Although rare, acute toxicity may be caused by ingestion of 500–1,000 mg sodium chloride/kg body weight. Symptoms include vomiting, ulceration of the gastrointestinal tract, muscle weakness and renal damage, leading to dehydration, metabolic acidosis and severe peripheral and central neural effects. Long-term effects of high (>6 g/day) dietary sodium chloride include the development of hypertension, and may increase the risk of kidney stone formation and left ventricular hypertrophy. In rodents, extremely high doses of sodium chloride during pregnancy caused musculoskeletal abnormalities, foetotoxicity and foetal death and post-implantation mortality and abortion. Sodium chloride has been demonstrated to be a gastric tumour promoter

Component	Human health hazard
	in experimental animals and high sodium chloride intakes have been associated with incidence of stomach cancer in human populations with traditional diets of highly concentrated, salted foods. (Expert Group on Vitamins and Minerals (2003), www.food.gov.uk/science/ouradvisors/vitandmin/evmpapers)
Zinc bromide ($ZnBr_2$)	Zinc bromide inhalation can cause severe irritation of mucous membranes and upper respiratory tract. Symptoms may include burning sensation, coughing, wheezing, laryngitis, shortness of breath, headache, nausea and vomiting. High concentrations may cause lung damage. Ingestion of zinc bromide can cause severe burns of the mouth, throat, and stomach. Can cause sore throat, vomiting and diarrhoea. Ingestions are usually promptly rejected by vomiting, but sufficient absorption may occur to produce central nervous system, eye and brain effects. Symptoms may include skin rash, blurred vision and other eye effects, drowsiness, irritability, dizziness, mania, hallucinations, and coma. Causes severe skin irritation with redness, itching and pain. May cause burns, especially if skin is wet or moist. Can cause severe eye irritation or burns with eye damage. Repeated or prolonged exposure by any route may cause skin rashes (bromaderma). Repeated ingestion of small amounts may cause central nervous system depression, including depression, ataxia, psychoses, memory loss, irritability and headache.
Calcium bromide ($CaBr_2$)	Calcium bromide brine is a highly concentrated aqueous solution of calcium bromide and calcium chloride. It is used extensively in the oil industry. This solution and its components are recognized as causes of skin injury and information is available from the manufacturers on their safe use and handling. Two patients who were injured following unprotected skin exposure to this solution and one patient who was injured following exposure to calcium chloride powder are reported. All sustained skin injuries characterized by an absence of pain and a delayed clinical appearance of the full extent of the injury. Furthermore healing was complicated by graft loss or was slow. Although organic bromine compounds are recognized as a cause of skin injuries, no previous reports of such injuries to humans secondary to calcium chloride or bromide exposure were found in the medical literature. Our experience with these patients is described. (Saeed *et al*., Burns; 23 (7–8)[32]. 1997. 634–637)
Sodium bromide (NaBr)	Sodium bromide is of low acute oral toxicity. Sodium bromide is expected to be a slight to moderate eye irritant. Repeated or prolonged skin contact may cause irritation and superficial burns. Available data indicate that sodium bromide may act as a teratogen (behavioural effects).
Sodium formate (NaCOOH)	Sodium formate is of low acute oral toxicity (LD50 oral rat > 3000 mg/kg). Data show that sodium formate is slightly irritating to the eye. Based on read-across from caesium formate, sodium formate is expected to be slightly irritating to skin. Sodium formate is not expected to be a skin sensitizer. Sodium formate at 1% in drinking water did not produce clinically adverse effects in rats after administration for approximately 18 months. Sodium formate is not genotoxic *in vitro* or *in vivo*. Based on read-across with calcium formate, sodium formate is not expected to be reprotoxic or carcinogenic.
Potassium formate (KCOOH)	Potassium formate is of low acute oral toxicity (LD50 oral mouse 5500 mg/kg). Data show that potassium formate is slightly irritating to the eye. Based on read-across from caesium formate, potassium formate is expected to be slightly irritating to skin. Potassium formate is not expected to be a skin sensitizer. Repeated-dose toxicity tests are not available; however, the metabolite formic acid did not cause significant toxicity to rats when administered in their drinking water at 0.5 and 1% for 2 to 27 weeks. Based on read-across with calcium formate, potassium formate is not expected to be reprotoxic or carcinogenic.
Caesium formate (CsCOOH)	Caesium formate solution (83%) is harmful upon ingestion (LD_{50} = 1780 mg/kg in rats), with clinical signs including depression, convulsions, respiratory distress, ataxia, and excessive salivation. Caesium formate monohydrate had low dermal (LD50 >2000 mg/kg) toxicity in rats, with signs of erythema noted at sites of application. Caesium formate solution (83%) was a slight skin irritant and a moderate eye irritant. Aqueous caesium formate (80% w/v) was not sensitizing to guinea pigs in a Buehler test. Repeated-dose toxicity tests are not available; however, the metabolite formic acid did not cause significant toxicity to rats when administered in their drinking water at 0.5 and 1 % for 2 to 27 weeks. The caesium cation is not expected to produce significant chronic toxicity. Caesium formate was not mutagenic in different *in vitro* assays. (National Industrial Chemicals Notification and Assessment Scheme (NICNAS), Australia, 2001).

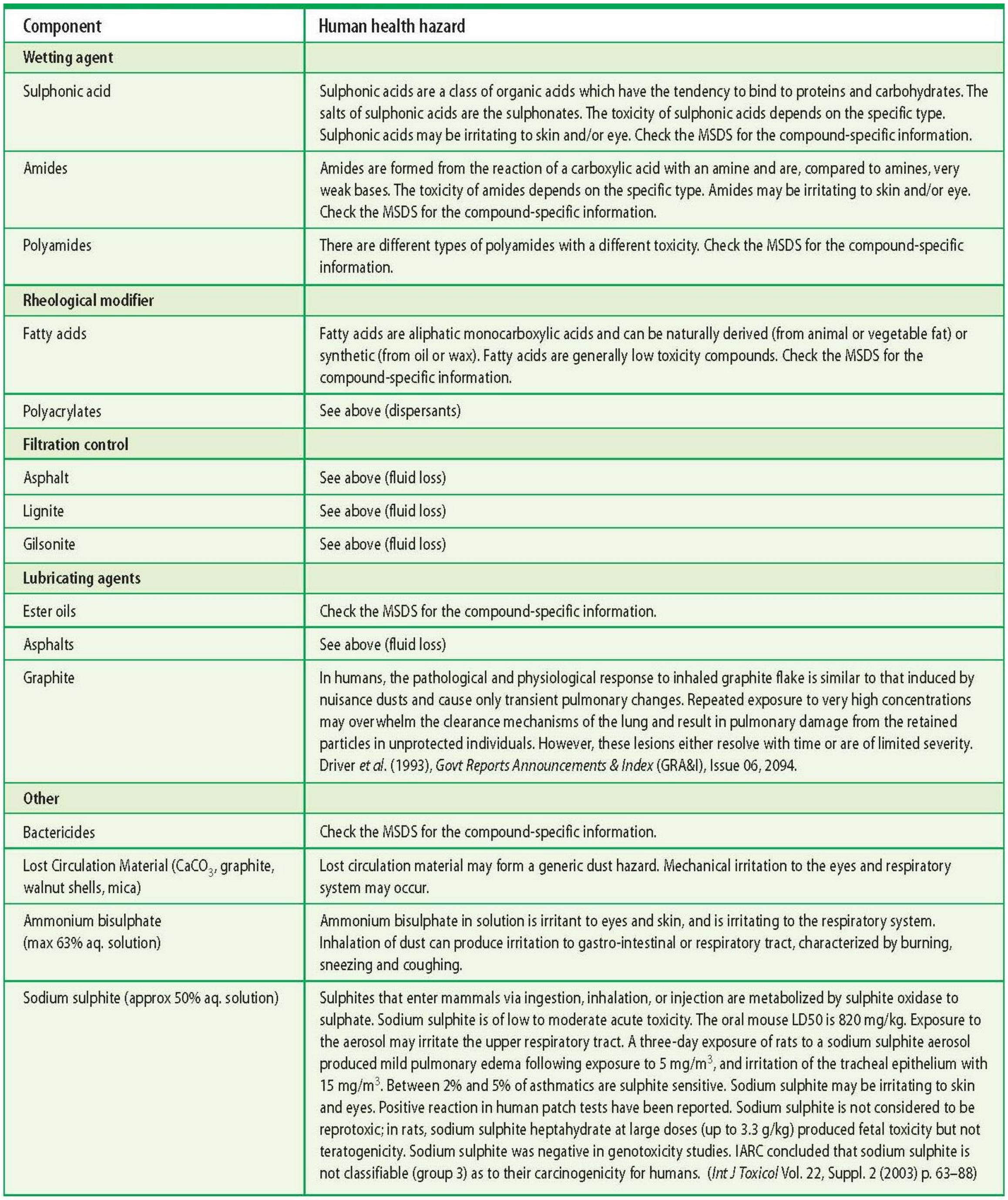
Component	Human health hazard
Density (weighting agents)	
Barite (Barium sulphate)	Studies in rats using a soluble salt (barium chloride) have indicated that the absorbed barium ions are distributed via the blood and deposited primarily in the skeleton. The principal route of elimination for barium following oral, inhalation, or intratracheal administration is in the faeces. Following introduction into the respiratory tract, the appearance of barium sulphate in the faeces represents mucociliary clearance from the lungs and subsequent ingestion. In humans, ingestion of high levels of soluble barium compounds may cause gastroenteritis (vomiting, diarrhoea, abdominal pain), hypopotassaemia, hypertension, cardiac arrhythmias, and skeletal muscle paralysis. Insoluble barium sulphate has been extensively used at large doses (450 g) as an oral radiocontrast medium, and no adverse systemic effects have been reported. No experimental data are available on barium sulphate; however, due to the limited absorption of barium sulphate from the gastrointestinal tract or skin, it is unlikely that any significant systemic effects would occur. The acute oral toxicity of barium compounds in experimental animals is slight to moderate. Barium nitrate caused mild skin irritation and severe eye irritation in rabbits. The lack of reports of skin or eye irritation in humans, despite its widespread use, suggests that barium sulphate, often used as a contrast medium, is not a strong irritant. Long-term studies of barium exposure in laboratory animals have not confirmed the blood pressure, cardiac, and skeletal muscle effects seen in humans and laboratory animals orally exposed to acutely high levels. Inhalation exposure of humans to insoluble forms of barium results in radiological findings of baritosis, without evidence of altered lung function and pathology. Animal studies involving respiratory tract instillation of barium sulphate have shown inflammatory responses and granuloma formation in the lungs; this would be expected with exposure to substantial amounts of any low-solubility dust, leading to a change in lung clearance and subsequently to lung effects. Currently available data indicate that barium does not appear to be a reproductive or developmental hazard. Barium was not carcinogenic in standard National Toxicology Program rodent bioassays. *In vitro* data indicate that barium compounds have no mutagenic potential. The critical end-points in humans for toxicity resulting from exposure to barium and barium compounds appear to be hypertension and renal function. The NOAEL in humans is 0.21 mg barium/kg body weight per day. (www.inchem.org/documents/cicads/cicads/cicad33.htm, Concise International Chemical Assessment Document 33, Barium and barium compounds.)
Calcium carbonate	Acute effects may include irritation of skin, eyes, and mucous membranes. Based on an oral LD50 in rats of 6,450 mg/kg, calcium carbonate is of low oral acute toxicity. There is no adequate evidence for a tumour-promoting or genotoxic action of calcium carbonate. Effects on reproduction have not been shown. High dietary levels inducing maternal toxicity resulted in decreased fetal weights and delayed skeletal and dental calcification in rats and/or mice. There may be a silicosis risk in using impure limestone or chalk containing (3–20%) quartz. No adverse health effects have been reported in the literature among workers using calcium carbonate. High oral doses did not produce systemic toxicity in laboratory animals. (Health Council of The Netherlands, 2003, calcium carbonate.)
Iron carbonate	Most data from iron compounds are derived from read-across with the ferrous salt iron sulphate. Ferrous sulphate has a low to moderate acute toxicity with a LD50 (rat) of 319–1,480 mg/kg. As ferrous sulphate is used in humans for the treament of anaemia, human data are also available. These indicate that the human LD50 is in the range of 40–1,600 mg/kg. Fatal doses are associated with gastric injury. Irritation data are scarce and indicate that ferrous sulphate may be irritating to skin and eyes. Ferrous sulphate is not a sensitizer. Genotoxicity data on ferrous sulphate are ambiguous. However. the overall weight of evidence from genotoxicity studies shows that ferrous sulphate is not genotoxic. Carcinogenicity is not expected. Ferrous sulphate is not a reprotoxicant. A study in calves fed up to 4000 ppm ferrous carbonate in diet shows that the calves were not affected. The tolerance for ferrous carbonate was higher than for ferrous sulphate.
Hematite	There are little data on hematite (or Fe_2O_3) available. The acute oral toxicity LD50 (rat) for Fe_2O_3 is greater than 10 g/kg. Upon eye contact some mechanical eye irritation may occur (dust). A carcinogenicity study in miners shows that haematite mining with low-grade exposure to radon daughters and silica dust was not associated with excess lung cancer in a relatively large cohort.
Ilmenite	There are no toxicity data available for ilmenite, or iron titanium oxide. It is expected that ilmenite is of low toxicity. There are no known hazards resulting from accidental ingestion of ilmenite sand as may occur during normal handling. Swallowing a large amount may result in irritation to the digestive system due to abrasiveness. Ilmenite dust may cause mechanical irritation of the eye. Ilmenite dust is regarded as general nuisance dust, but can be irritating if inhaled at high concentration. May cause symptoms such as coughing or sneezing.

Component	Human health hazard
Manganese tetroxide	Manganese tetraoxide is of low acute toxicity. Mn_3O_4 is not a skin irritant, nor a sensitizer. Mn_3O_4 dust may cause some mechanical irritation to the eye. Results from a repeated dose study in monkeys and rats exposed to 11.6, 112.5 and 1,152 µ Mn_3 as Mn_3O_4 aerosol 24 h/day for 9 months, show no exposure related effects on pulmonary function, limb tremor or electromyographic activity. There are several reports about manganese toxicity as a result of exposure to fume/vapour from elemental manganese and by inhalation of pyrolusite (MnO_2). Long-term inhalation (years) of manganese oxides may cause chronic manganese intoxication affecting the central nervous system, potentially leading to extensive disablement. Health risk of MnO_2 (widely described in literature) may be different from that of MnO, Mn_2O_3, and Mn_3O_4. The differences in oxidation states of the element Mn in these compounds may affect their bioavailability and distribution and thus their potential effects.
Viscosity	
Bentonite (or other clays)	An important determinant of the toxicity of bentonite and other clays is the content of quartz (SiO_2). Exposure to quartz is causally related to silicosis and lung cancer. Statistically significant increases in the incidence of or mortality from chronic bronchitis and pulmonary emphysema have been reported after exposure to quartz. Single intratracheal injection into rodents of bentonite and montmorillonite with low content of quartz produced dose- and particle size-dependent cytotoxic effects, as well as transient local inflammation, the signs of which included oedema and, consequently, increased lung weight. Single intratracheal exposures of rats to bentonite produced storage foci in the lungs 3–12 months later. After intratracheal exposure of rats to bentonite with a high quartz content, fibrosis was also observed. Bentonite increased the susceptibility of mice to pulmonary infection. No adequate studies are available on the carcinogenicity of bentonite. Long-term occupational exposures to bentonite dust may cause structural and functional damage to the lungs. However, available data are inadequate to conclusively establish a dose-response relationship or even a cause-and-effect relationship due to limited information on period and intensity of exposure and to confounding factors, such as exposure to silica and tobacco smoke. (*Environmental Health Criteria*, Vol. 231 (2005) 159 p.)
Organophillic clay (montmorillonite, attapulgite, hectorite)	In general, the acute toxicity of organophillic clays is low. Some organophillic clays are used in cosmetics. Data on a hectorite clay show that the clay is of low acute and repeated dose toxicity. The clay is not a skin or eye irritant, nor a skin sensitizer. In dust form the hectorite clay may cause mechnical eye irritation. Data indicate that the hectorite clay is not genotoxic. Data on reprotoxicity and carcinogenicity are not available. Check the MSDS for the compound-specific information.
Biopolymers	The biopolymers used are generally low toxicity compounds. Some of these biopolymers are also used as food additive. Check the MSDS for the compound-specific information.
Carboxymethyl cellulose	Carboxymethyl cellulose is of low toxicity. Carboxymethyl cellulose is approved for and used as food additive. (*WHO Food Additives Series*, Vol. 42 (1999) pp 175–9)
Polyanionic cellulose	Cellulose compounds are generally low toxicity compounds. Some of these cellulose compounds are also used as food additive. Check the MSDS for the compound-specific information. (*WHO Food Additives Series*, Vol. 40 (1998) pp 55–78; and *WHO Food Additives Series* Vol. 42 (1999) pp 175–9)
Guar gum (polysaccharide)	Guar gum is a low toxicity compound, commonly used as food additive. Allergic rhinitis following repeated inhalation exposure to guar gum dust has been reported. (Lagier *et al.*, 1990, *J. Allergy Clin Immun*, 85(4) p. 785–790; Kanerva *et al.*, 1988, *Clin Allergy*, 18(3) p245–252)
Emulsifiers	
Soaps	See Table 2. Several emulsifiers may irritate skin and/or eye and may be harmful by inhalation or if swallowed. Check the MSDS for the compound-specific information.
Amines	See Table 2. Several emulsifiers may irritate skin and/or eye and may be harmful by inhalation or if swallowed. Check the MSDS for the compound-specific information.
Imidazolines	See Table 2. Several emulsifiers may irritate skin and/or eye and may be harmful by inhalation or if swallowed. Check the MSDS for the compound-specific information.
Polyamides	See Table 2. Several emulsifiers may irritate skin and/or eye and may be harmful by inhalation or if swallowed. Check the MSDS for the compound-specific information.

Component	Human health hazard
Dispersants	
Modified polyacrylates	Modified polyacrylates is a general term for several specific polyacrylates each having compound-specific toxicological properties. Check the MSDS for the compound-specific information.
Lignosulphonates	Lignosulphonates are complex polymers with a broad range of molecular mass and are derived from trees. The wood from trees is composed mainly of three components—cellulose, hemicellolose and lignin. In the sulphite pulping process, the lignins are sulphonated so they become water soluble and thus can be separated from the insoluble cellulose. A review of available toxicity data on several lignosulphonates by the US EPA indicated that lignosulphonates are of very low toxicity (www.epa.gov [Federal Register: February 16, 2005 (Volume 70, Number 31)]). The oral acute LD50 values are all greater than 2 g/kg. Repeated dose studies indicate NOAELs and LOAELs in the order of magnitude of g/kg/day. There is some (unsubstantiated) information that lignosulphonates given to rats before, during, and after mating at doses as high as 1,500 mg/kg/day did not cause adverse effects on reproduction or offspring. But at a dose level of 500 mg/kg/day there were histopathological changes in the lymph nodes of the mothers. There were no concerns identified for the mutagenicity or carcinogenicity of lignosulphonates. Based on the physical/chemical properties, and particularly on the large molecular weights of the lignosulphonates, lignosulphonates are not likely to be absorbed via any route of exposure. The only health effects of concern upon exposure to lignosulphonates are irritation of skin, eyes and respiratory system. For some lignosulphonates contact allergy has been reported (Andersson *et al.*, 1980; Contact Dermatitis 6(5): 354–355). The toxicity depends on the type and size of the lignosulphonate. Check the MSDS for the compound-specific information.
Tannins	Tannins are polyphenols derived from plants. Due to their ubiquitous presence in food they have been subject of many toxicity studies. In general, tannins are of low acute toxicity. Tannins in food have been associated with several beneficial and adverse health effects (Chung *et al.*, 1998 *Crit Rev Food Sci Nutr* 38(6): 421–64). IARC has evaluated tannic acid and tannins and concluded that although tannins were carcinogenic in animals upon subcutaneous injection, no epidemiological evidence in humans was available to evaluate their toxicity in humans. (IARC *Monographs on the Evaluation of the Carcinogenic Risk of Chemicals to Man: Some Naturally Occurring Substances*, Vol. 10, pages 253–262). Check the MSDS for the compound-specific information.
Fluid loss	
Synthetic polymers	Check the MSDS for the compound-specific information.
Carboxymethyl celullose	See above (viscosity)
Polyanionic cellulose	See above (viscosity)
Starch	Starch is a low toxicity compound, commonly used as food additive.
Bentonite	See above (viscosity)
Modified lignites	Modified lignites are derived from brown coal. The toxicity mainly depends on the modification. Check the MSDS for the compound-specific information.
Asphalt	Asphalt, more commonly referred to as bitumen in Europe, is a dark brown to black, cement-like semisolid or solid or viscous liquid produced by the non-destructive distillation of crude oil during petroleum refining. When asphalts are heated, vapours are released; as these vapours cool, they condense. As such, these vapours are enriched in the more volatile components present in the asphalt and would be expected to be chemically and potentially toxicologically distinct from the parent material. Asphalt itself is considered to be of low toxicity. Asphalt fumes are the cloud of small particles created by condensation from the gaseous state after volatilization of asphalt. Symptoms associated with asphalt fume exposure are eye, nose, and throat irritation and coughing. These health effects appear to be mild in severity and transient in nature. Additional symptoms include skin irritation, pruritus, rashes, nausea, stomach pain, decreased appetite, headaches, and fatigue, as reported by workers involved in paving operations, insulation of cables, and the manufacture of fluorescent light fixtures. Asphalt fumes and vapours may be absorbed following inhalation and dermal exposure. Results of several *in vitro* mutagenicity studies on asphalt fumes are ambiguous. Results of carcinogenicity studies indicate that some asphalt fume condensates can cause tumours when applied dermally to mice. A meta-analysis of 20 epidemiological studies failed to find overall evidence for a lung cancer risk among pavers and highway maintenance workers exposed to asphalt. Under various performance specifications, it is likely that asphalt fumes contain carcinogenic substances. (*Concise International Chemical Assessment Document* (CICAD) Vol. 59 (2004))

Component	Human health hazard
Resins	There are several types of resins, both naturally derived and synthetic. The toxicological properties vary. Some resins have been associated with skin irritation and allergic contact dermatitis. Check the MSDS for the compound-specific information.
Gilsonite	Gilsonite is a form of natural asphalt found in large amounts in the Uintah Basin of Utah. Workers can be exposed to the dust of gilsonite and to the fumes of gilsonite when heating or boiling the material. Gilsonite dust may cause mechanical eye irritation, while the fumes may be irritating to the eyes and respiratory system (Fairhall (1950) *Industrial Hygiene Newsletter*, 10(5): 9-10). Industrial hygiene characterizations were performed by NIOSH at three gilsonite mills and nine gilsonite mining operations to measure occupational exposure to gilsonite and its constituents and to evaluate potential health effects (Kullman *et al.*, *Am Ind Hyg Assoc J* (1989) 50(8): 413–418). Six out of seven bulk gilsonite samples had crystalline silica contents below 0.75% wt., no asbestos or other fibrous mineral compounds were detected in bulk samples from five different veins of gilsonite, and polynuclear aromatic hydrocarbons were not detected in any bulk samples. The authors conclude that the gilsonite dust exposure data are consistent with results of an earlier respiratory health survey of gilsonite workers in which the most definitive finding was an excess prevalence of bronchitic symptoms. The respiratory health survey (Keimig *et al.*, *Am J Ind Med.* (1987); 11(3): 287–296) showed that increased prevalences of cough and phlegm were found in workers with high-exposure jobs, but no evidence for dust-related pulmonary function impairment was noted.
Inhibition	
Salts	See above (osmotic—salts)
Glycols (polyglycols)	Glycols, glycol ethers and polyglycols have different toxicities. Polyglycols are generally of low toxicity. Check the MSDS for the compound-specific information.
Silicate	The most commonly used silicates in drilling fluids are potassium silicate and sodium silicate. These ingredients combine metal cations (potassium or sodium) with silica to form inorganic salts. Sodium silicate administered orally acts as a mild alkali and is readily absorbed from the alimentary canal and excreted in the urine. The toxicity of silicates has been related to the molar ratio of $Si0_2/Na_20$ and the concentration. Potassium and sodium silicates have a low to moderate acute toxicity. Rats orally administered 464 mg/kg of a 20% solution containing either 2.0 or 2.4 ratio to 1.0 ratio of sodium oxide showed no signs of toxicity, whereas doses of 1,000 and 2,150 mg/kg produced gasping, dypsnea, and acute depression. A case report describes that neutralized sodium silicate produced vomiting, diarrhea, and gastrointestinal bleeding in human. Dermal irritation of potassium silicate and sodium silicate ranged from negligible to severe, depending on the species tested and the molar ratio and concentration tested. Potassium silicate was non-irritating in two acute eye irritation studies in rabbits. Sodium silicate was a severe eye irritant in acute eye irritation studies. A skin freshener (10% of a 40% aqueous solution) containing sodium silicate was non-irritating. Sodium silicate in another three eye irritation studies was highly irritating, irritating, and nonirritating, respectively. Detergents containing 7%,13%, and 6% sodium silicate mixed 50/50 with water were negligible skin irritants to intact and abraded human skin. A 10% of a 40% aqueous solution of sodium silicate was negative in a repeat-insult predictive patch test in humans. The same aqueous solution of sodium silicate was considered mild under normal use conditions in a study of cumulative irritant properties. Sodium silicate tested in elbow crease studies and semioccluded patch tests, produced low grade and transient irritation. Repeated dose studies in Beagles and rats showed no overt signs of toxicity. Sodium silicate was non-mutagenic in a standard bacterial assay. Reprotoxicity studies with sodium silicate in rats showed some effects on the number of offspring at high doses but no effects on male rat fertility. (*Int J Toxicol* Vol. 24 Suppl. 1 (2005) pp 103–7)
Polyacrylamides (partially hydrolysed)	There are various different types of polyacrylamides. Check the MSDS for the compound-specific information.
pH control	
Sodium hydroxide (NaOH)	Sodium hydroxide is a skin and eye corrosive. In a human 4-hour patch test, sodium hydroxide (0.5%) was a very clear skin irritant. Irritation of the nose, throat, or eyes was observed in workers engaged in cleaning operations and in a small number of users of an oven spray. Ingestion might be fatal, as a result of, e.g., shock, infection of the corroded tissues, pulmonary necrosis, or asphyxia. No increase in mortality in relation to duration or intensity of exposure to caustic dust was found in a group of 265 workers for periods ranging from less than 1 year to up to 30 years. (Health Council of The Netherlands, 2000, sodium hydroxide)

Component	Human health hazard
Potassium hydroxide (KOH)	Potassium hydroxide is a skin and eye corrosive. Following ingestion of (a solution of) potassium hydroxide, rapid corrosion and perforation of the oesophagus and stomach, stricture of the oesophagus, violent pain in throat and epigastrium, haematemesis, and collapse may occur. When inhaled in any form, potassium hydroxide is strongly irritating to the upper respiratory tract. Acute exposures may cause symptoms in the respiratory tract including severe coughing and pain. Additionally, lesions may develop along with burning of the mucous membranes. Inhalation may be fatal as a result of spasm, inflammation, and oedema of the larynx and bronchi, chemical pneumonitis, and pulmonary oedema (which can develop with a latency period of 5–72 hours). Chronic exposures may cause inflammatory and ulcerative changes in the mouth and possibly bronchial and gastrointestinal disorders. It has been reported that 10% of workers exposed to KOH during the production of ascorbic acid developed allergic dermatitis. At least one case of oesophageal carcinoma at the site of hydroxide-induced strictures has been reported. In mice, repeated applications of aqueous solutions (3-6%) of KOH to the skin for 46 weeks resulted in an increased incidence of skin tumours. Since tumourigenesis was associated with severe skin damage inducing marked epidermal hyperplasia, a non-genotoxic mechanism is assumed. (Health Council of The Netherlands, 2004, potassium hydroxide)
Calcium hydroxide ($Ca(OH)_2$) Lime	Acute exposures to calcium hydroxide may cause irritation, along with coughing, pain, and possibly burns of the mucous membranes with, in severe acute exposures, pulmonary oedema and hypotension with weak and rapid pulse. Solid calcium hydroxide is corrosive to the eyes and may cause severe injury to the skin. There are numerous case reports on accidental exposures to calcium hydroxide resulting in corneal and skin alkali burns and caustic ulcers. Generally, these effects are caused by the solid material and less commonly or rarely by solutions. Ingestion of alkali is reported to be followed by severe pain, vomiting (containing blood and desquamated mucosal lining), diarrhoea, and collapse. Two epidemiological studies that addressed the association between cement-dust exposure and stomach cancer were considered insufficient to reach any conclusions on the association between cement dust exposure and stomach cancer. However, no adverse effects have been experienced by long-term exposed workers. Oral LD50 values of approximately 7,300 mg/kg bw were reported for rats and mice. No adequate repeated-dose toxicity (including carcinogenicity and reproduction toxicity) or genotoxicity/mutagenicity studies are available. (Health Council of The Netherlands, 2004, calcium hydroxide)
Citric acid	Based on many experimen tal data in animals and on human experience, citric acid is of low acute toxicity. The NOAEL for repeated dose toxicity for rats is 1200 mg/kg/d. The major, reversible (sub)chronic toxic effects seem to be limited to changes in blood chemistry and metal absorption/excretion kinetics. Citric acid is not suspected of being a carcinogen nor a reprotoxic or teratogenic agent. The NOAEL for reproductive toxicity for rats is 2500 mg/kg/d. Further, it is not mutagenic *in vitro* and *in vivo*. Also, the sensitizing potential is seen as low. In contrast, irritation, in particular of the eyes but also of the respiratory pathways and the skin, is the major toxicological hazard presented by citric acid. (SIDS. *Screening Information Data Set for High Production Volume Chemicals*, 2004)
Sodium bicarbonate ($NaHCO_3$)	Sodium bicarbonate is of low acute toxicity. Oral LD50 values are higher than 4,000 mg/kg bw, and an inhalation study in rats using a concentration of 4.74 mg/l inhalable dust produced no deaths. Sodium bicarbonate is slightly irritating to the skin and eye of rabbits. There is no indication of any adverse effects of long-term use or exposure via any route. *In vitro* bacterial and mammalian cell tests showed no evidence of genotoxic activity. Sodium bicarbonate is not a reprotoxicant. Based on the available information there are no indications that sodium bicarbonate has carcinogenic effects. Sodium bicarbonate has a long history of use in food and normal handling and use will not have any adverse effects. Acute oral ingestion of high doses may result in a ruptured stomach due to excessive gas development. Acute or chronic excessive oral ingestion may cause metabolic alkalosis, cyanosis and hypernatraemia. These conditions are usually reversible, and will not cause adverse effects. (SIDS. *Screening Information Data Set for High Production Volume Chemicals*, 2003)
Calcium oxide (CaO; Quick lime)	Occupational and accidental exposures have shown calcium oxide to be very irritating and corrosive to mucous membranes, eyes, and moist skin because of local liberation of heat and dehydration of tissues upon slaking of the small size particles and the resulting alkalinity of the slaked product (calcium hydroxide). Fatal burns have been reported after massive exposure. Calcium oxide was stated not to be sensitizing in an open epicutaneous test. Calcium oxide can cause severe irritation and burns to the eyes, oedema, hyperaemia, lachrymation, blurred vision, corneal opacities, ulceration, and perforation and loss of vision. Inflammation of the respiratory passages, ulceration, perforation of the nasal septum, and pneumonia have been attributed to inhalation of calcium oxide dust. Workers in lime factories for up to 40 years have experienced no ill effects from exposure to lime. (Health Council of The Netherlands, 2006, calcium oxide)



Component	Human health hazard
Wetting agent	
Sulphonic acid	Sulphonic acids are a class of organic acids which have the tendency to bind to proteins and carbohydrates. The salts of sulphonic acids are the sulphonates. The toxicity of sulphonic acids depends on the specific type. Sulphonic acids may be irritating to skin and/or eye. Check the MSDS for the compound-specific information.
Amides	Amides are formed from the reaction of a carboxylic acid with an amine and are, compared to amines, very weak bases. The toxicity of amides depends on the specific type. Amides may be irritating to skin and/or eye. Check the MSDS for the compound-specific information.
Polyamides	There are different types of polyamides with a different toxicity. Check the MSDS for the compound-specific information.
Rheological modifier	
Fatty acids	Fatty acids are aliphatic monocarboxylic acids and can be naturally derived (from animal or vegetable fat) or synthetic (from oil or wax). Fatty acids are generally low toxicity compounds. Check the MSDS for the compound-specific information.
Polyacrylates	See above (dispersants)
Filtration control	
Asphalt	See above (fluid loss)
Lignite	See above (fluid loss)
Gilsonite	See above (fluid loss)
Lubricating agents	
Ester oils	Check the MSDS for the compound-specific information.
Asphalts	See above (fluid loss)
Graphite	In humans, the pathological and physiological response to inhaled graphite flake is similar to that induced by nuisance dusts and cause only transient pulmonary changes. Repeated exposure to very high concentrations may overwhelm the clearance mechanisms of the lung and result in pulmonary damage from the retained particles in unprotected individuals. However, these lesions either resolve with time or are of limited severity. Driver *et al*. (1993), *Govt Reports Announcements & Index* (GRA&I), Issue 06, 2094.
Other	
Bactericides	Check the MSDS for the compound-specific information.
Lost Circulation Material ($CaCO_3$, graphite, walnut shells, mica)	Lost circulation material may form a generic dust hazard. Mechanical irritation to the eyes and respiratory system may occur.
Ammonium bisulphate (max 63% aq. solution)	Ammonium bisulphate in solution is irritant to eyes and skin, and is irritating to the respiratory system. Inhalation of dust can produce irritation to gastro-intestinal or respiratory tract, characterized by burning, sneezing and coughing.
Sodium sulphite (approx 50% aq. solution)	Sulphites that enter mammals via ingestion, inhalation, or injection are metabolized by sulphite oxidase to sulphate. Sodium sulphite is of low to moderate acute toxicity. The oral mouse LD50 is 820 mg/kg. Exposure to the aerosol may irritate the upper respiratory tract. A three-day exposure of rats to a sodium sulphite aerosol produced mild pulmonary edema following exposure to 5 mg/m^3, and irritation of the tracheal epithelium with 15 mg/m^3. Between 2% and 5% of asthmatics are sulphite sensitive. Sodium sulphite may be irritating to skin and eyes. Positive reaction in human patch tests have been reported. Sodium sulphite is not considered to be reprotoxic; in rats, sodium sulphite heptahydrate at large doses (up to 3.3 g/kg) produced fetal toxicity but not teratogenicity. Sodium sulphite was negative in genotoxicity studies. IARC concluded that sodium sulphite is not classifiable (group 3) as to their carcinogenicity for humans. (*Int J Toxicol* Vol. 22, Suppl. 2 (2003) p. 63–88)

Appendix G: Particle Size and Inhalation Effects (from IPIECA & OGP *Drilling fluids and health risk management* [Appendix 7])

Substances which can be inhaled or are respirable include gases, vapours and aerosols: aerosols are particles and may have gases or vapours adsorbed onto their surface or dissolved into them. These substances can be defined as follows:

- Gases: substances which normally exist in gaseous form at standard pressure and temperature.
- Vapours: gaseous form substances normally liquid at standard pressure and temperature.
- Aerosols: suspension of variable size particles capable of remaining airborne.
- Dusts: caused by mechanical abrasion or fragmentation of solids; the size of particles is 0.1 microns (μm) to 100 μm.
- Fumes: produced by combustion, sublimation or condensation of volatile solids, the size of particle is usually less than 0.1 μm, but fumes have a tendency to flocculate and produce larger particles as the aerosol ages
- Smokes: suspension of solid particles produced by incomplete combustion of organic materials; size of particle usually less then 0.5 μm and particles do not settle readily.
- Mists and fogs: condensation or liquid particles, which produce liquid aerosols.

Particle size will determine where in the respiratory tract particles will dispose. Larger particles (>10 microns) will generally dispose in the upper respiratory tract whereas smaller particles (<10 microns) will generally dispose in the lower respiratory tract such as the bronchial and the alveoli.

The fraction smaller than 10 μm which is able to reach the alveoli is called the respirable fraction.

Particle deposition in the respiratory tract

Aerodynamic diameter (size in μm)	Behaviour
>100	Unlikely to be inhaled.
100–30	Can be inhaled at the smaller end of the range but unlikely to be absorbed into the body unless the particles are very soluble.
30–10	Will penetrate into the bronchial part of the respiratory system but will gradually be cleared. Some absorption into the rest of the body may occur due to the long residence time unless very insoluble.
10–1	Particles in this aerodynamic size range will be carried into the alveoli.
<1	At less than one micron a substantial percentage will remain suspended in the air and will be breathed out.

Acronyms and Abbreviations

ACGIH American Conference of Governmental Industrial Hygienists

ASTM American Society for Testing and Materials

BHA Bottom Hole Assembly

BOP Blowout Preventer

BTEX Benzene, Toluene, Ethylbenzene, and Xylene

CCOHS Canadian Centre for Occupational Health and Safety

CDC Center for Disease Control

IARC International Agency for Research on Cancer

MOC Management of Change

MSDS Material Safety Data Sheet

NIOSH The National Institute for Occupational Safety and Health

OEL Occupational Exposure Level

OH&S Occupational Health and Safety

PAH Polyaromatic Hydrocarbons

PPE Personal Protective Equipment

THC Total Hydrocarbons

TLV Threshold Limit Value

TWA Time Weighted Average

WHMIS Workplace Hazardous Material Information System

Glossary

Aniline Point The lowest temperature at which equal volumes of aniline ($C_6H_5NH_2$) and the oil base form a single phase (i.e., the aniline is fully dissolved in the oil). Since the aniline point correlates roughly with the amount and type of aromatic hydrocarbons in the oil, a test of the aniline point may be used to determine aromatic exposure risk and the extent to which the oil is likely to damage elastomers in the circulation system (e.g., rubber seal elements). A lower aniline point indicates higher levels of aromatics, while a higher aniline point indicates lower levels of aromatics. (based on Schlumberger Oilfield Glossary)

Arenes see Aromatics.

Aromatics Hydrocarbons that share the “benzene ring” structure of benzene (C_6H_6) and typically carry a sweet scent. Aromatic hydrocarbons can be monocyclic (MAH) or polycyclic (PAH). Aromatics are also referred to as arenes.

Blowout An uncontrolled flow of formation fluids from a well that cannot be contained using previously installed barriers and typically require specialized intervention. (based on Schlumberger Oilfield Glossary)

Blowout Preventer (BOP) The large valve on the top of a well that may be closed if the drilling crew loses control of formation fluids. By closing this valve (typically remotely via hydraulic actuators), the drilling crew usually regains control of the reservoir and procedures can then be initiated to increase the fluid density until it is possible to open the BOP and retain pressure control of the formation. A “BOP stack” may offer a variety of control measures including annular-type preventers that close around a variety of pipe sizes and ram-type preventers that are designed to close around a set diameter drillpipe, shear rams that can cut the drillpipe, and blind rams that close on an open hole. (based on Schlumberger Oilfield Glossary)

Carcinogen A substance that can cause cancer.

Centrifuge A cone-shaped drum designed to remove fine and ultrafine solids from drilling fluid. Drilling fluid is fed into one end of the drum that rotates at 2000 to 4000 rpm with separated solids exiting at the other end. (based on Schlumberger Oilfield Glossary)

Closed Cup Flash Point Test A test procedure used to measure the flash point of a material. With a closed cup, the sample is heated and stirred within a closed container preventing the vapour from escaping, as an ignition source is introduced at a regular interval. The temperature at which the vapour ignites is its flash point (the temperature at which the vapour pressure reaches the lower flammable limit). A closed cup flash point is generally lower than a flash point measured using an open cup method.

Combustible A WHMIS classification for a liquid that has a flashpoint equal to or greater than 37.8°C (100°F) and but less than 93.3°C (200°F). As such they are typically less of a fire hazard than flammable liquids. See **Flammable**.

Cuttings Small pieces of rock that break away due to the cutting action of the drill bit teeth. These are screened out of the drilling fluid at the shale shakers. Samples of cuttings are regularly collected and are monitored and analyzed for composition, size, shape, color, texture, hydrocarbon content and other properties by a mud logger, drilling fluid engineer (aka “mud man”), and/or other onsite personnel.

Dermal Exposure Contact between the skin and a potentially harmful chemical substance.

Dermatitis A localized inflammation of the skin that may include redness, heat, swelling, pain, blisters, scales or crusts. As an occupational illness, “contact dermatitis” may be caused either by a chemical exposure that irritates the skin and is localized to the contact area or by an allergic reaction in which case the dermatitis may occur in other places on the body that did not come in contact with the allergy-causing material. (based on CCOHS MSDS Glossary of Terms)

Desander A hydrocyclone device that removes drill solids from the drilling fluid. Fluid is pumped into the wider upper section and as the fluid flows around the cone shape, the centrifugal forces separate out the solids which exit at the bottom of the cone while the cleaner lighter liquids exits through piping at the top of the hydrocyclone. Desanders are located downstream of the shale shakers and degassers but before desilters or mud cleaners. (based on Schlumberger Oilfield Glossary)

Desilter A hydrocyclone much like a desander except that its design incorporates a greater number of smaller cones. The smaller cones allow the desilter to efficiently remove smaller diameter drill solids than a desander does. As such, it is located downstream from the desander. (based on Schlumberger Oilfield Glossary)

Dilution Ventilation The removal of contaminated air from a general area and bringing in clean air, thereby diluting the amount of contaminant workers are exposed to in a given work area. This is also known as “General Ventilation”. (based on CCOHS MSDS Glossary of Terms)

Drill Bit The tool at the bottom of a drill string used to crush or cut rock as part of a rotational motion. Drilling fluid is pumped through the drill bit to cool the bit and remove the cuttings. It must be changed when it becomes dull or stops making progress. (based on Schlumberger Oilfield Glossary)

Drillpipe Steel pipe with special threaded ends called tool joints. Threaded end to end on the rig floor during operations, the drillpipe connects the rig surface equipment with the bottomhole assembly (BHA) and serves as the conduit to pump drilling fluid to the bit as well as allowing the drill crew to raise, lower and rotate the bottomhole assembly and drill bit. (based on Schlumberger Oilfield Glossary)

Drill String The combination of the drillpipe, the bottomhole assembly (BHA), and any other tools used to make the drill bit turn at the bottom of the wellbore.

Elastomer Any natural or synthetic rubber material capable of recovering its original shape after being stretched. Elastomers provide permanent or temporary seals in a variety of situations and equipment, especially well control equipment, used in drilling operations.

(Chemical) Exposure As used in IRP 14, any contact between the human body and potentially harmful chemicals through inhalation, skin contact, or ingestion.

Exposure Control Plan A documented plan that outlines how an employer will manage potentially harmful chemical exposure risks on a worksite. It will typically contain items such as statements on purpose and responsibilities, hazard identification, risk assessment and controls, education and training requirements, written work procedures, hygiene facilities and decontamination procedures, health monitoring, and documentation requirements and be subject to periodic review. “Exposure Control Plan” is a term specifically drawn from WorkSafeBC legislation (OHS Regulation 5.54) but other provincial regulation, such as Alberta’s requirements on “code of practice” (OHS Code 4.26) and Saskatchewan’s requirement for “a written procedure” (OHS Regulations 307) demand similar documentation.

Flammable A WHMIS categorization for a liquid that has a flashpoint of less than 37.8 (100°F). These will usually ignite and burn easily at normal working temperatures. See **Combustible**.

Flash Point The lowest temperature at which a liquid or solid gives off enough vapour to form a flammable air-vapour mixture near its surface—the lower the flash point, the greater the fire hazard. (based on CCOHS MSDS Glossary of Terms)

Formation Short hand for “geological formation”, it refers to a body or layer of rock that is sufficiently distinctive and continuous. It is often used in relation to the geological formation that contains hydrocarbons (e.g., “formation fluids” would be gas or oil contained in a given body of rock released by the drilling operation).

Hydrocarbons A variety of organic compounds consisting entirely of hydrogen and carbon. Typically created from decomposed organic matter, hydrocarbons can be gases (e.g., methane, propane), liquids (e.g., hexane, benzene), or waxes or low melting solids (e.g., paraffin wax, naphthalene) or polymers (e.g., polyethylene, polypropylene).

Invert A term often loosely used interchangeably for an oil based drilling fluid. It technically refers to an “invert emulsion oil mud/drilling fluid” where water is dispersed in an oil base that serves as the continuous phase. The term arises in distinction to an emulsion in which oil is dispersed in a continuous phase of water.

Kick A (typically unplanned) flow of formation fluids into the wellbore during drilling operations when the pressure in the borehole generated by the hydrostatic pressure of the drilling fluid is lower than the pressure of the fluid in the formation and so fails to counterbalance that pressure. Kicks generally occur either because the fluid weight is lower than specified or the drilled formation has a higher pressure than anticipated.

Local Exhaust Ventilation The removal of contaminated air directly at its source. Since local exhaust ventilation does not allow the hazardous material to enter the work environment, it is more effective than dilution or general ventilation in reducing worker exposure for more hazardous airborne materials. (based on CCOHS MSDS Glossary of Terms)

Material Safety Data Sheet (MSDS) A document on a given material that contains information on the potential health effects of exposure and how to work safely with the material It includes hazard evaluations on the use, storage, handling, and emergency procedures related to the material. In Canada, all products or material covered by the Controlled Products Regulations (part of WHMIS) require an MSDS before the product or material can be used in the workplace. (based on CCOHS MSDS Glossary of Terms)

Occupational Exposure Limit (OEL) The maximum concentration of a chemical in the workplace air to which most people can be exposed without experiencing harmful effects. These limits are expressed in various ways, often based on the length of exposure (see time-weighted average [TWA] and short-term exposure limit [STEL]) or expressed as a ceiling exposure limit (C) that should not be exceeded at any time. (based on CCOHS MSDS Glossary of Terms)

Oil Base Mud (OBM) A drilling fluid with a hydrocarbon base (continuous phase). The term is sometimes used more loosely but more strictly it refers to fluids with a base derived from raw or refined crude oil (e.g., diesel, kerosene, mineral oils) and as such distinct from synthetic base mud (SBM).

Personal Protective Equipment (PPE) Clothing or devices that work to isolate or mitigate direct exposure to a hazardous material or situation. Typical PPE includes fire-resistant (FR) coveralls, high visibility vest, fall protection safety harness, hard hat, dust or chemical mask for respiratory protection, safety glasses or face shield, nitrile or leather gloves, etc. PPE occupies the lowest level of the hierarchy of hazard controls as it may be unreliable and, if it fails, the worker is left unprotected. (based on CCOHS MSDS Glossary of Terms)

Sensitization The development, over time, of an allergic reaction to a chemical. The chemical may cause a mild response on the first few exposures but, as the allergy develops, the response becomes worse with subsequent exposures. Eventually, even short exposures to low concentrations can cause a very severe reaction. (based on CCOHS MSDS Glossary of Terms)

Short-Term Exposure Limit (STEL) This is the occupation exposure limit based on the average concentration of a chemical over a short period (typically 15 minutes) that a worker can be exposed to without experiencing irritation, long-term or irreversible tissue damage, or reduced alertness. The number of times the concentration reaches the STEL and the amount of time in between these occurrences may also be restricted. (based on CCOHS MSDS Glossary of Terms)

Synthetic Base Mud (SBM) A drilling fluid with a synthetic fluid. The base fluid in SBM is manufactured using chemically modified hydrocarbon components rather than whole crude oil and/or synthesized from other raw materials.

Threshold Limit Value (TLV) The occupational exposure limit (OEL) established by the American Conference of Governmental Industrial Hygienists (ACGIH). Some governments adopt TLVs as their legal exposure limits. See further occupational exposure limit (OEL). (based on CCOHS MSDS Glossary of Terms)

Time-Weighted Average Exposure Limit (TWA) An occupational exposure limit (OEL) based the average concentration calculated using the duration of exposure to different concentrations of the chemical during a specific time period—typically using an 8 hour period. With this method, higher and lower exposures are averaged over the day. Calculations are required to readjust these in the event of longer daily shifts (e.g., 12 hour shifts). (based on CCOHS MSDS Glossary of Terms)

Total Hydrocarbon (THC) A term to describe a measurable mixture of hydrocarbon compounds often involving similar or additive health effects.

References

International Association of Oil and Gas Producers (OGP) in conjunction with the International Petroleum Industry Environmental Conservation Association (IPIECA), 2009. *Drilling fluids and health risk management: A guide for drilling personnel, managers and health professionals in the oil and gas industry* (OGP Report Number 396, http://www.ogp.org.uk/pubs/396.pdf).