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Fire-resistant hydraulic fluids — Classification and specification — Guidelines on selection for the protection of safety, health and the environment

ICS 75.120

National foreword

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— present to the responsible international/European committee any enquiries on the interpretation, or proposals for change, and keep UK interests informed;

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Fire-resistant hydraulic fluids - Classification and specification - Guidelines on selection for the protection of safety, health and the environment

Fluides difficilement inflammables - Classification et spécification - Principes directeurs de sélection de fluides et de considération des risques de sécurité et d'environnement

Schwerentflammbare Druckflüssigkeiten - Klassifikation und Spezifikation - Auswahlrichtlinien ur Gewährleistung von Sicherheit, Gesundheit und Umweltschutz

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Contents

Page

Foreword 3
Introduction 4
1 Scope 5
2 Normative references 5
3 Terms and definitions 5
4 General requirements 6
5 Classification of fire-resistant fluids 7
6 Compliance with essential health and safety requirements (EHSR) 8
7 Hazard identification 10
8 Risk estimation 13
9 Hazard control measures 14
10 Continuity of properties 16
Annex A (informative) Examples for local regulations applying to the approval and use of hydraulic fluids 17
Annex B (informative) Fire-resistance tests and guidance on performance 18
Annex C (informative) Examples of fire risk assessment procedures for hydraulic fluids 22
Annex D (informative) Tests suitable for monitoring the condition of hydraulic fluids in service 35
Bibliography 37

Foreword

This CEN Technical Report (CEN/TR 14489:2005) has been prepared by Technical Committee CEN/TC 19 “Petroleum products, lubricants and related products”, the secretariat of which is held by NEN.

This document has been prepared under mandate M/238 given to CEN by the European Commission and the European Free Trade Association along with other standards on fire-resistant hydraulic fluids to be complementary to the regulatory measures contained in various EU Directives.

The mandated work of CEN/TC 19 is to develop European Standards for specifications and testing conditions applicable to fire-resistant hydraulic fluids.

Introduction

The function of this Technical Report is to provide suppliers and users of equipment guidance on how compliance with the essential health and safety requirements (EHSR's) incorporated in both Product (Article 95) and User (Article 137/138) Directives issued by the European Union may be achieved in respect of the use of fire-resistant hydraulic fluids. It builds upon the guidance provided in EN 1050 on the principles of risk assessment. EN 1050 in turn supports Directive 92/104/EEC [1].

The document was considered necessary because the specialised nature of fire-resistant fluids and the tests used to quantify their properties may not in general be familiar to prospective machinery manufacturers and users. Because several Directives deal with the prevention of fire it is necessary to consider other aspects in addition to the tests used to quantify fire properties.

The use of fire-resistant hydraulic fluids is a fire protection measure. A fire occurs if combustible materials or explosive gases, oxygen and an ignition source are all present at the same time. If there is a danger of an ignition source being present when hydraulic installations are in use, one method of improving safety may be to replace more combustible mineral oil by a fire-resistant hydraulic fluid. Fire-resistant fluids provide fire protection. Their use, however, shall not jeopardise other safety measures as, in addition to requirements for fire resistance, there are additionally requirements for assessing effects on the health of workers and, increasingly, on potential effects on the environment. Guidance on the information needed is contained in this Technical Report.

IMPORTANT — This document does not purport to address all of the safety problems associated with the use of hydraulic systems. It is concerned with the use of fire-resistant fluids as a means of reducing the risk of fire. It is the responsibility of the user of this document to establish appropriate safety and health practices to reduce other safety risks and to determine the applicability of regulatory regimes.

1 Scope

This Technical Report gives guidance on the achievement of compliance with Essential Health and Safety Requirements (EHSR) by the selection of fire-resistant fluids or by other means. It includes consideration of the selection of fluids with lower levels of fire resistance and of mineral oil, with appropriate additional safety measures, where this option may be considered to be most satisfactory during operation.

This Technical Report is concerned with assessing the fire resistance, health properties and effects on the environment, but does not cover requirements for their general physical and chemical properties, which are detailed in EN ISO 12922.

2 Normative references

The following referenced documents are indispensable for the application of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

EN 1050:1996, *Safety of machinery - Principles for risk assessment.*

EN ISO 2592, *Determination of flash and fire points – Cleveland open cup method (ISO 2592:2000).*

EN ISO 6743-4, *Lubricants, industrial oils and related products (class L) – Classification – Part 4: Family H (Hydraulic systems) (ISO 6743-4:1999).*

EN ISO 12922, *Lubricants, industrial oils and related products (class L) - Family H (Hydraulic systems) - Specifications for categories HFAE, HFAS, HFB, HFC, HFDR and HFDU (ISO 12922:1999, including Technical Corrigendum 1:2001)).*

EN ISO 14935, *Petroleum and related products – Determination of wick flame persistence of fire-resistant fluids (ISO 14935:1998).*

ISO 3448, *Industrial liquid lubricants - ISO viscosity classification.*

ISO 7745, *Hydraulic fluid power – Fire-resistant (FR) fluids – Guidelines for use.*

3 Terms and definitions

For the purposes of this Technical Report, the following terms and definitions apply.

3.1
safety
freedom from unacceptable risk

[ISO/IEC Guide 51:1999]

3.2
risk
combination of the probability of occurrence of harm and the severity of that harm

[ISO/IEC Guide 51:1999]

3.3
harm
physical injury or damage to the health of people, or damage to property or the environment

[ISO/IEC Guide 51:1999]

3.4
hazard
potential source of harm

[ISO/IEC Guide 51:1999]

3.5
hazardous event
event that can cause harm

3.6
safety measure
means that eliminates a hazard or reduces a risk

3.7
risk assessment
overall process comprising a risk analysis and a risk evaluation

[ISO/IEC Guide 51:1999]

3.8
risk analysis
systematic use of available information to identify hazards and to estimate the risk

[ISO/IEC Guide 51:1999]

3.9
risk evaluation
procedure based on the risk analysis to determine whether the tolerable risk has been achieved

[ISO/IEC Guide 51:1999]

3.10
environmental properties
chemical or physical properties of a hydraulic fluid which may interact with the environment

3.11
fire resistance
ability of a fluid to fulfil an expected duty in standard fire resistance tests

3.12
fire-resistant
having the property of fire resistance according to one or more standard test methods

4 General requirements

In circumstances where it is necessary to use hydraulic fluids, an assessment is needed as to whether fire-resistant fluids may be the best option for reducing the risk of fire starting and spreading. Where fire-resistant fluids are chosen they shall make an overall contribution towards improving safety. Hence they shall not only meet requirements for fire resistance but also for the protection of the health of workers and the environment and, shall not jeopardise other safety measures that may be in use. The primary reason for selecting fire-resistant fluids is to protect against the risk of fire: protection of the environment may be achieved by methods other than the properties of the fluids.

In some countries in the European Union (EU) and European Free Trade Association (EFTA) governments operate approval schemes for hydraulic fluids or impose local regulations, which require that particular levels of performance be met in specific tests to allow fluids to be used in certain industrial situations (see Annex A).

Compliance with these schemes and regulations is considered by the regulatory authorities in those countries to constitute compliance with the appropriate EU Directives for the application of hydraulic fluids. It should be noted that such regulations take precedence over CEN standards, and potential suppliers and users of hydraulic fluids should establish whether approval schemes or local regulations exist.

Annex A contains a list of the countries that operate approval schemes for hydraulic fluids or impose local regulations.

Fire-resistant hydraulic fluids shall conform to the specifications laid down for the various industries by the European Authorities and/or the certification authorities of each member state according to the risks arising in each industry, distinguishing if necessary between installations giving rise to greater or lesser hazards. Certification shall be carried out with reference to the specifications and standards issued by the European or national authorities and should be based on the tests contained in Annex B and C of this Technical Report.

5 Classification of fire-resistant fluids

Table 1 lists the main categories of fire-resistant fluids as found in EN ISO 6743-4, their compositions and applications.

Fire-resistant fluids in accordance with EN ISO 6743-4 are hydraulic fluids which are classified as fire-resistant in accordance with particular fire test procedures. They achieve their fire resistance either because they contain water or because their chemical composition confers fire resistance. Only water and fire-resistant fluids of type HFA with water content above 90 % are considered to be non-combustible. Fire-resistant fluids do, however, require a substantially greater input of energy to cause ignition than conventional mineral oil hydraulic fluids and may not sustain combustion after leaving the ignition source.

The level of fire resistance shall be established by the use of a range of standard protocols (for guidance see Annex B). In the event that a test representing the particular circumstance of use is not included in EN ISO 12922 then data from other fire-resistance tests having adequate precision may be invoked, subject to local regulations.

Table 1 — Categories of fire-resistant fluids, their compositions and applications according to EN ISO 6743-4

Type [a] Symbol	Composition	Typical applications and operating temperature range [b]
1. AQUEOUS FLUIDS[e]		
HFAE [b]	Oil-in-water emulsions. Emulsifying oil content less than 20 % by mass and typically in the range 1 % to 5 % by mass.	Hydraulic systems in continuous casting plant, mine roof supports. Operating temperature range 5 °C to 50 °C.
HFAS [c]	Chemical solutions in water. Concentrate content less than 20 % by mass and typically 1 % to 5 % by mass.	Hydraulic systems in continuous casting plant, mine roof supports. Operating temperature range 5 °C to 50 °C.
HFB and HFB LT	Water-in-oil emulsions. Mineral oil content approximately 60 % by mass, “LT” designation indicates emulsions that are stable at low temperatures	Hydrostatic systems in coal mines. Operating temperature range 5 °C to 50 °C.
HFC	Water polymer solutions. Water content not less than 35 % by mass	Hydrostatic systems in steel plant and coal mines. Operating temperature range –20 °C to 50 °C.
2. ANHYDROUS FLUIDS		
HFDR	Synthetic fluids containing no water and consisting of phosphate esters	Hydrodynamic couplings, operating temperature up to 150 °C and hydrostatic transmissions, operating temperature range –20 °C to 70 °C.
HFDU [d]	Synthetic fluids containing no water and of other composition	Hydrostatic transmissions operating temperature range –20 °C to 70 °C.

[a] Viscosity grade according to ISO 3448. The viscosity grades most commonly encountered are 32, 46, 68 and 100.

[b] See ISO 7745 for additional information.

[c] The viscosity of HFAE and HFAS fluids that contain 95 % or more of water is very close to that of water and is usually not measured. These fluids are given the viscosity 1.

[d] Fluids that fall within the HFDU category are defined imprecisely with respect to their chemical compositions. The most widely used group of fluids that currently fall within this classification are the synthetic esters.

[e] Water-containing fluids should not be used when processing magnesium, as explosive gases maybe formed.

6 Compliance with essential health and safety requirements (EHSR)

6.1 General

Where national approval schemes or local regulations exist (Annex A) and where compliance with these schemes or regulations is considered by the regulatory authorities to constitute compliance with the appropriate EHSR’s given in EU Directives for the application of the hydraulic fluid, suppliers and users shall ensure that hydraulic fluids are submitted to the appropriate bodies for certification.

Where approval schemes or local regulations do not exist or where compliance with them does not constitute compliance with the appropriate EU Directives, compliance with the EHSR's may be achieved by:

either

- the selection of hydraulic fluids that have fire-resistance, health and environmental properties appropriate to the circumstances of use;

or

- the use of other safety measures in conjunction with, or instead of, certain fire-resistance, health and environmental properties.

Selection of the optimum safe system can be achieved by adopting a risk assessment approach according to the principles in EN 1050.

6.2 Need for detailed information

Because the water content and chemical composition of fire-resistant fluids may vary, not only from type to type, but also from one product to another within a type, levels of fire resistance, health effects and environmental properties may also vary. It follows that a fluid that is suitable for use in one circumstance and provides compliance with the EHSR's may not be suitable for other applications.

The initial step towards compliance with the EHSR's is to carry out a logical examination of the circumstances in which both the hydraulic fluid and the system are to be used so that the hazards that are present may be determined (see Clause 7). Following this, an assessment is carried out to identify the consequences of the hazards in terms of the possible effects of the occurrence of the hazardous event on people, property and the environment (see Clause 8) so that the safety measures that need to be taken to control or to eliminate the hazards or to reduce risks can be determined. These safety measures may include, but may not be confined to, the use of fire-resistant fluids (see Clause 9).

It shall be remembered that other hazards that are not dealt with in this standard may exist and shall be the subject of separate risk assessments. Annex A of EN 1050:1996 gives examples of hazards, hazardous situations and events.

6.3 Information needed

The following basic information is needed for compliance assessment.

a) Circumstances of use for both the hydraulic fluid and the system so that the EHSR's contained in the Directives that are relevant to those circumstances may be ascertained.

b) Performance required of the hydraulic fluid in service by the end user or equipment manufacturer.

c) Determination of all hazards associated with the use, including foreseeable misuse (see Clause 7) and foreseeable failure conditions.

d) Health and Safety Data Sheets for candidate hydraulic fluids.

e) Performance of candidate hydraulic fluids in appropriate tests to assess fire resistance, effects on health and effects on the environment (see Clause 9).

f) Information on procedures for the disposal and waste treatment of candidate fluids.

It is also desirable to have available the following information.

g) Any experience with certified fire-resistant hydraulic fluids in the particular use or in similar circumstances.

h) Any experience in the particular use with other hydraulic fluids of the same chemical type as that under consideration.

i) Any experience with other hydraulic fluids in the particular use or in similar circumstances.

j) Any accident history and any information regarding damage to health or the environment.

Directive 67/548/EEC [3] (as amended by the Seventh Amendment 92/32/EEC [4]) and Directive 1999/45/EC [5] require suppliers of all substances to provide Health and Safety Data Sheets on their products that give information relating to the health and safety of persons and the effect of the product on the environment. Requirements for the general structure and content of Health and Safety Data Sheets are set out in Directive 91/155/EEC [6] (as amended by Directive 93/112/EC [7]).

The Directive requires the data sheets to:

- indicate the presence of components that have adverse health effects;
- give appropriate risk and safety phrases;
- identify the hazards that the product presents both to persons and to the environment;
- provide information on first aid measures, fire-fighting, exposure controls and personal protection;
- provide toxicological and ecological information.

NOTE 1 The data sheets may not contain all of the information needed to comply with the EHSR's and to allow control of all of the hazards that are identified in Clause 7 and that might be associated with hydraulic fluids.

NOTE 2 It is desirable at this stage to consider the use of hydraulic fluids that contain recycled components or readily biodegradable fluids (see ISO 15380 [8]) in order to minimise the impact on the environment where technical requirements permit.

7 Hazard identification

7.1 Fire hazards

The fire hazards potentially present in the situation under examination shall be determined.

The following fire hazards are directly related to the use of hydraulic fluids under fault conditions.

a) Ignition of combustible vapours produced by hydraulic fluid.

b) Ignition of hydraulic fluids ejected under pressure from hydraulic systems in the form of a spray.

c) Ignition of hydraulic fluid spilled during transport or leaking from hydraulic systems on to absorbent material such as lagging or combustible dust and the subsequent propagation of fire along the absorbent material.

d) Ignition of a fluid stream or pool.

e) Ignition of hydraulic fluids when the fire resistance has been reduced by chemical or physical changes in the fluid caused by service operation.

EXAMPLE 1 Reduction of fire resistance due to evaporation or separation of the water content which provides fire resistance for some types of fluid.

f) Ignition of fire-resistant fluid contaminated with more combustible substances.

EXAMPLE 2 Contamination of fire-resistant fluid by mineral oil where system changeover procedures for the conversion to the use of fire-resistant fluid have not been made correctly.

NOTE EN 1710 [9], which contains specifications for equipment intended for use in potentially explosive atmospheres in mines, contains provisions for an allowed maximum temperature of machine surfaces, which are limited not to exceed 150 °C.

7.2 Sources of ignition

The ignition sources potentially present in the situation under examination shall be determined.

Sources of ignition such as spark, flames, electric arcs, high surface temperatures, acoustic energy, optical radiation and electromagnetic waves are potentially present in underground mines[1)] They are also likely to be present in other work situations. Possible situations in which these sources of ignition may occur are given below. The list shall not be taken as being exhaustive:

— discharge of static electricity;

— stray electric currents or discharges from malfunctioning electricity supply equipment, which could produce overheating of surfaces or sparks capable of causing ignition;

— friction between moving surfaces or the entrapment of foreign bodies between moving surfaces caused, for example, by failures of mechanical plant, causing localised overheating;

— high surface temperatures in the workplace arising from the presence of molten materials or materials undergoing high temperature manufacturing operations;

— high surface temperatures present in the braking systems, transmissions, or exhausts of internal combustion engines;

— use of smoking or other materials that may be contraband in some industrial situations;

— existing fires caused by the ignition of other combustible materials in the workplace.

Other ignition sources that may be present include open flames, welding spatter and sparks from grinding operations. The importance of long periods of exposure to low grade sources of heat, which may, for example, remove water from water-containing fluids, shall be considered.

7.3 Consequences of combustion

The risk assessment shall take account of the consequences of combustion in terms of obscuration of exits, increased escape times, exposure to toxic products, local high temperatures and the possibility of the spread of fire.

Combustion may result in:

- the production of smoke and/or steam, which may obscure exits and result in longer escape times;
- the production of toxic gases, the effects of which will depend on the nature of the products, the local ventilation and escape conditions;
- high local temperatures, which may result in personnel being engulfed in flame or suffering immobilisation due to burns; and

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1) These sources of ignition have been identified in European Council Directive 92/104/EEC.[1]

- the spread of fire.

7.4 Health hazards

The principal hazards to health, that shall be considered in relation to the use of hydraulic fluids, are the following.

a) Acute oral toxicity.

b) Irritant effect on the skin.

c) Irritant effect on the eyes.

d) Inhalation toxicity of the fluid as an aerosol.

e) Inhalation toxicity of thermal decomposition products.

f) Allergic reactions or other results of repeated or long-term exposure.

g) Filter self-rescuers. These are provided to workers for protection against the presence of carbon monoxide in the event of fire. In some countries, possible blocking of these self-rescuers is considered as an additional hazard.

Some or all of these hazards may be present in industries other than mining. The health hazards potentially present in the situation under examination shall be determined.

7.5 Environmental hazards

The possibility of escape of hydraulic fluid into the environment during storage, transport, use or disposal shall be determined so that the environmental hazards potentially present may be considered and appropriate system design modifications made, if necessary.

If hydraulic fluids escape into the environment or are not disposed of in a proper manner, they may potentially have effects on:

- water-toxicity to aquatic organisms, including:
  - — potential to bioaccumulate;
  - — depletion of oxygen content;
  - — persistence in the environment (biodegradability).
- soil-potential to contaminate groundwater and sources of drinking water, including:
  - — potential to bio-accumulate,
  - — persistence in the environment (biodegradability).

They are unlikely to have effects on air unless thermal decomposition occurs in the event of an accidental exposure to a heat source, when the effect will be local to the combustion.

Hydraulic fluids can escape into the environment during transport, storage or use. It is important, therefore, that the correct types of storage tanks and vessels for transportation are used and are correctly identified to indicate the contents. Means of transporting fluids should be appropriate to minimise the likelihood of escape into the environment. Measures such as collection trays to avoid spillage during filling should be considered.

Separate and properly labelled tanks should be used for the collection of waste fluids intended for reprocessing or disposal.

Local regulations may require particular aspects of environmental impact to be considered, including storage, transport, use and disposal.

NOTE Readily biodegradable fire-resistant hydraulic fluids of the type HFA, HFC, HFDR and HFDU are available. The HFDU products are similar to HEES products, which are in accordance with specification ISO 15380 [8].

8 Risk estimation

The possible risks associated with the hazards identified in Clause 7 shall be estimated for each situation of use of hydraulic fluid so that the control measures needed for those hazards may be identified. EN 1050 contains detailed guidance on risk estimation, i.e. evaluating the consequences of hazards.

Consideration shall be given to the following.

a) The severity of harm that a hazard may cause to persons, property or the environment.

b) If the harm is caused to persons, the numbers involved and the extent of the harm e.g. slight (reversible), serious (irreversible) or death.

c) The probability of occurrence of that harm which is a function of the frequency and duration of exposure to the hazard, the probability of occurrence of the hazardous event and the possibilities to avoid or limit the harm.

EXAMPLE

The consequences of a fire where:

— escape is relatively easy;

— limited numbers of persons may be exposed to the harm;

— exposure may be intermittent;

— the consequences of exposure to the hazard may be slight;

may be judged to be far less serious in terms of the harm that may be caused to persons than a similar fire in a restricted environment such as a tunnel or an underground mine where:

— escape is difficult;

— potentially all of the workforce underground may be exposed to the effects of fire;

— potential exposure is over an extended period;

— the consequences of exposure to the hazard may include death.

Experience with hydraulic fluids in the particular use or in similar circumstances, accident histories and information regarding damage to health that might be available will assist in evaluating the probability of occurrence of harm.

9 Hazard control measures

9.1 General

Hazard control may be achieved by selecting a fluid that is less hazardous, or by the use of other safety measures, e.g. mechanical fire protection equipment (safeguarding), or by a combination of these two.

The determination of what is “less hazardous” is achieved by subjecting fluids to a variety of criteria as defined in 9.2, 9.3 and 9.4, the results of which give some measure of their fire resistance, health effects and environmental properties. The level of fire resistance of a fluid, i.e. the primary safety measure, considered to be necessary may depend on whether secondary safety devices, e.g. fire suppression systems, are available at the site of application. Similarly, the health effects considered acceptable may vary depending on, for example, the risk of exposure, or the availability of protective clothing and washing facilities.

For the purpose of the fire hazard assessment process, if information to the contrary is not available it shall be assumed that the fluid performs no better than mineral oil. For all industrial situations it is advisable to carry out a final assessment to determine whether compliance with the EHSR’s has been achieved after considering all of the performance requirements.

9.2 Control of fire hazards

The reduction of fire hazards may be achieved in a number of ways, including:

- use of fire-resistant fluids;
- design of machinery e.g. to prevent access of hydraulic fluid to ignition sources (see ISO 4413);
- provision of fire suppression systems that can reduce the hazards;
- use of smaller volumes of hydraulic fluids;
- removal of potential ignition sources;
- combinations of some or all of these; and
- lower pressures.

NOTE 1 Lower system pressures can reduce the hazard by decreasing the mechanical stress on the system and by reducing the amount of fluid escaping. However, as a fluid release may still occur with subsequent ignition, the use of this technique by itself to reduce the hazards is not recommended.

To assist in the reduction of fire hazards, by selecting the optimum fire-resistant fluid, information can be obtained from a variety of sources including, but not limited to, the following:

— well-established and standardised laboratory fire tests that are used to assess fluid performance;

— large and small scale tests representative of specific circumstances of use;

— expert judgement based on information from other sources e.g. fire chemistry and toxic nature of products of combustion;

— operational experience e.g. levels of performance that have been found acceptable in some industrial situations.

It is important to realise that no single fire resistance test can provide a full assessment of the fire resistance of a fluid. Consideration shall be given to a range of tests that are appropriate to the hazards identified for a particular application. The range of standardised fire resistance tests currently available does not cover all possible release scenarios and ignition sources (see Clause 5).

Annex B contains information on a number of fire resistance tests that are currently standardised either in CEN or ISO, together with levels of performance in these tests that have been found to be satisfactory in particular circumstances.

NOTE 2 Fire resistance tests are not required for HFA fluids where they contain more than 90 % of water.

Examples of how the above approach may be applied are given in Annex C.

9.3 Control of health hazards

9.3.1 General

The following methodology has been found satisfactory to establish whether a fluid represents a health hazard in the conditions under which it is likely to be used.

a) Review of all the available toxicological data on the base stocks and additives present, including safety data sheets.

b) Examination of the results of tests carried out when it has been found necessary to carry these out because of inadequate data.

c) Examination of reports on the health of persons who have been in contact with the fluid during manufacture or testing.

This methodology is equally applicable to situations other than mines.

The following paragraphs provide information to facilitate the use of this methodology. It should be noted that freedom from toxicity shall only be demonstrated by the presence of appropriate data; the absence of data cannot be taken to indicate that toxic effects are not present. If data are not present appropriate tests shall be carried out.

9.3.2 Review of available data

The review of the available toxicological data shall include the performance of and experience with fluids of similar chemical composition. Directives 67/548/EEC [3] and 98/24/EC [10] (including their subsequent additions and amendments such as 92/69/EC) may be used to determine the necessary data which can assist in the evaluation of a fluid.

9.3.3 Test procedures

In the majority of cases it is possible to use the information supplied under the requirements of Directives 67/548/EEC [3] (including their subsequent additions and amendments) and Directive 98/24/EC [10] to give the necessary information. Other appropriate tests may be invoked when data from other sources are considered inadequate.

The test methods are based on those described in European Council Directive 67/548/EEC [3], but other methods regarded as more stringent and more specific to exposure conditions in mines are included. For example, three particular areas of concern in mines and other extractive industries were identified.

a) Skin irritation - the possibility of extended and widespread skin contact and the general unavailability of washing facilities underground.

b) Aerosol toxicity - the escape of fluids under high pressure into the breathing zone of workers.

c) Toxicity of thermal decomposition products of fluids, where the possibility of escape of persons from the working place is limited.

The test methods in the annex of Directive 67/548/EEC [3] do not address the hazards presented by aerosol toxicity or by thermal decomposition products. If these hazards are considered to be present, other appropriate recognised test methods may be used.

9.3.4 Effects of long term exposure

Test methods are available to examine the potential for allergic reactions or other long-term effects of exposure to the fluid and its degradation products (see 67/548/EEC [3]). This information may also be available as a result of long-term use in other applications.

9.4 Control of environmental hazards

Where the risk assessment has indicated that hazards to the environment potentially exist because of the escape during storage, or transport, or use, or because of the improper disposal of fluids, the environmental impact of candidate fluids shall be examined so that the need for measures to control possible environmental contamination can be determined.

The suppliers' Health and Safety Data Sheets should provide information on the potential environmental hazards presented by their products in terms of the hazards identified in 7.5.

NOTE 1 As a minimum, data on the relevant physico-chemical properties of fluids and on acute fish toxicity should be examined to assess environmental impact. Part A of the annex to European Council Directive 67/548/EEC [3] describes test methods for the generation of data on physico-chemical properties relevant to the environmental hazard assessment. Part C of that annex [3] contains guidelines for the conduct of acute fish toxicity studies.

NOTE 2 The guidelines in the annex to Directive 67/548/EEC [3] and Directive 87/302/EEC [11], Part C, are suitable for assessing biodegradability, as defined in Directive 91/325/EEC [12].

NOTE 3 Procedures for the determination of bioaccumulation in and elimination from fish are described in OECD Guidelines, protocols 305A – 305E [13].

Local regulations may impose restriction on compositions or usage of hydraulic fluids.

10 Continuity of properties

The properties of hydraulic fluids may change with service operation and the safety standards considered necessary from the risk assessment may not be met after a period of use. For example, the fire resistance of water-containing fluids may be reduced by the evaporation of the aqueous phase, HFB fluids can split into individual water and oil phases, fluids can become contaminated with mineral oil and some HFD fluids can contain polymeric thickeners which may degrade with use, having an adverse effect on fire resistance.

Hydraulic fluids shall continue to meet the safety standards considered necessary from the assessment and the appropriate test requirements given in Clause 9 during the whole of their operational life.

Appropriate fluid monitoring and maintenance routines will assist in ensuring that this requirement is met. Annex E lists tests that are appropriate for monitoring the condition of hydraulic fluids in service. These tests do not necessarily provide direct measures of the primary properties, such as fire resistance, of a fluid but provide measures of fluid condition that may be related to the primary properties. Advice shall be sought from fluid manufacturers/suppliers on appropriate tests to monitor the relevant properties.

Annex A
(informative)

Examples for local regulations applying to the approval and use of hydraulic fluids

The following list contains existing local regulations, which will, in all cases, override standards and other advisory documents. This list does not purport to be exhaustive. The national regulations can be more stringent than necessarily required by the corresponding European Directives.

A.1 Regulations in France

NOTE To be put in at a later stage

A.2 Regulations in Germany

— § 15 of "Allgemeine Bundesbergverordnung (ABBergV)", October 23, 1995 (BGBl I S. 1466), gives directions for underground work places in mines;

— "Bergverordnung zum gesundheitlichen Schutz der Beschäftigten" (Gesundheitschutz- Bergverordnung – GesBergV), July 31, 1991 (BGBl I S 1751), gives directions for non mineral oil based hydraulic fluids

— BGR 137 "Regeln für Sicherheit und Gesundheitsschutz beim Umgang mit Hydraulikflüssigkeiten" (formerly ZH 1/215 April 1997), issued by "Berfusgenossenschaftliche Zentrale für Sicherheit und Gesundheit (BGZ)

A.3 Regulations in the United Kingdom

NOTE To be put in at a later stage

Annex B
(informative)

Fire-resistance tests and guidance on performance

B.1 Introduction

This annex is intended to provide information on the range of ISO/CEN standardized fire test methods that are available to assist in the evaluation of the suitability of a fluid for a particular application.

In the event that a test representing the particular circumstance of use is not included in EN ISO 12922, then data from other tests appropriate to the hazard and with adequate precision may be invoked, subject to local regulations.

The use of particular test methods to assess the fire hazard in a given situation may not be necessary where the hazard assessment procedure has indicated that:

- machine design is such that fluid is effectively shielded from ignition sources;
- there are no sources of ignition present;
- the volume of fluid is small and the hazard resulting from ignition is low; and
- additional safety measures such as fire suppression systems are installed to control this hazard and provide a safe situation.

B.2 Ignition of a spray of fluid

B.2.1 Test description

B.2.1.1 Available test methods

Three methods of test, which involve attempting to ignite a spray of fluid under defined conditions, have been developed to control the fire hazard caused by the ignition of a spray of fluid:

a) Spray ignition test - Hollow cone nozzle method,
set out in EN ISO 15029-1 [14];

b) Spray ignition test with screen,
set out in NF E48-618 [15];

c) Spray ignition test - Stabilised flame heat release method,
to be developed as EN ISO 15029-2 [16];

Performance in Hollow cone nozzle method is not necessarily related to performance in the other two methods.

B.2.1.2 Spray ignition test - Hollow cone nozzle method

This method provides a pass or fail criterion based on persistence of burning.

B.2.1.3 Spray ignition test with screen

In this method results are expressed as rating 1, 2 or 3. The fluid shall achieve rating 1 or 2 in five consecutive tests.

B.2.1.4 Spray ignition test - Stabilised flame heat release method

In this method the ignitability of the fluid is measured by the amount of heat it releases. An ignitability factor (the Ignitability Index, RI) is calculated on the basis of the heat released by the burning fluid spray. In addition it is possible to measure smoke production (the Optical Density of Smoke Index, D) and flame length (the Flame Length Index, RL).

B.2.2 Performance of spray ignition tests

B.2.2.1 General

Different spray tests produce varying forms of output. Many produce pass/fail criteria based on a duration of burning, the occurrence of ignition or of a pre-determined flame length. Such outputs are less useful than a continuous performance scale as is given, for example, by tests such as the stabilised flame heat release method which can provide a measure of the hazard in terms of either the rate of heat release or the rate of production of smoke. These measures are more scientifically-based and are closely related to the true hazards of burning fluids.

B.2.2.2 Performance of spray ignition test - Hollow cone nozzle method

This test indicated the time between removal of the igniting flame and extinction of the combustion of the spray (usually less or more than 30 s).

B.2.2.3 Performance of spray ignition test with screen

This test provides two ratings:

— rating 1 the jet of fluid does not ignite

— rating 2 the jet of fluid ignites, but the flame does not reach the screen.

B.2.2.4 Performance of spray ignition test - Stabilised flame heat release method

In this test the fire hazard is expressed using three continuous ranking measures. The primary parameter is the Ignitability Index, RI, which is closely related to the rate at which combusting fluid releases heat. Additionally, the length of the flame produced (a measure of the potential for spread of fire) and the rate at which combusting fluid produces smoke can be used to quantify the hazards of combusting fluid. The former is expressed in terms of a Flame Length Index, RL, while the latter uses a Smoke Index, D, closely related to the optical density of smoke in the exhaust of the test rig.

Using these measures, this test is capable of distinguishing between the performance of all fluids currently in commercial use on the basis of three principal fire hazards.

The test also provides scope for classifying fluids into performance bands based on the values of these three parameters measured in the test. During development an initial scheme based on the ignitability index using eight bands (A-H) was derived so that fluids with RI values which placed them in the three higher performance bands were suitable for use where high energy ignition sources are either frequently or constantly present. Similarly those fluids with a RI which placed them in the next three bands were considered suitable in locations where fault conditions might give rise to ignition sources such as electrical discharges or hot surfaces. It was considered that fluids falling into the lower categories should only be used alongside additional safety measures.

The test provides scope for the development of other potentially simpler and coarser classification schemes if required.

Historically fluids with a RI value which places them in bands A to C have given a satisfactory performance in French and German coal mines and in bands A to D in the United Kingdom.

NOTE Due to potential precision problems that might not support the use of eight classes in this method, it is envisaged that the number of bands will possibly be reduced to three or four.

B.3 Flame propagation test

B.3.1 Test method

EN ISO 14935 (the Wick Test) has been found to be adequate to measure the fire resistance of fluids when soaked into absorbent or combustible materials and the extent to which the fluids will allow an incipient flame to persist and hence propagate fire. In this test a flame is applied to a wick that has been soaked in the fluid under test under defined conditions and the persistence of burning after the removal of the flame is measured.

B.3.2 Performance

The hazard from fluid soaking into absorbent material is controlled satisfactorily if the fluid records a “pass” when tested according to the method given in EN ISO 14935, in that no propagation and minimal persistence of burning occurs.

B.4 Ignition of a fluid stream or pool by hot surfaces

B.4.1 Test description

Two tests have been used to assess the hazard caused by the ignition of fluid by hot surfaces. They are set out in DIN 51794 [17] and EN ISO 20823 [18]. Several other test methods may be applicable here as well, like EN ISO 2592 or other suitable flash point or fire point test methods. See also B.5.

DIN 51794 is suitable for fluids with ignition temperatures between 75 °C and 650 °C. In this test fluid is heated and the temperature at which the fluid ignites spontaneously, i.e. without the provision of an external ignition source, is measured.

EN ISO 20823 has been found suitable to control this hazard where temperatures of hot surfaces may be as high as 800 °C. In this test, fluid is poured on to a tube heated to 704 °C and observations are made as to whether the fluid:

— flashes or burns on the tube, but does not after dripping from the tube or in the collecting pan beneath the tube;

— does not flash or burn on the tube, but does do so after dripping from the tube;

— does not flash or burn on the tube or after dripping from the tube.

Experience has shown that for the rating of non-aqueous fluids performance in DIN 51794 and EN ISO 20823 are comparable, but for water-containing fluids performance in the two tests is not necessarily related.

B.4.2 Performance

Where the energy of the ignition source (the hot surface) is relatively low and mineral oils are being considered, experience has shown that a safe situation exists if the maximum temperature of hot surfaces is at least 20 % below the ignition temperature of the mineral oil hydraulic fluid as measured by DIN 51794.

NOTE This limits temperatures of hot surfaces to less than 250 °C.

Where the energy of the ignition source is relatively high, to achieve a safe situation the fluid should not flash or burn either on the tube or after dripping from the tube in the Manifold Ignition Test (EN ISO 20823).

Depending upon the temperature of the hot surfaces present, the Manifold Ignition Test can be carried out at temperatures lower than 704 °C and up to 800 °C, giving the opportunity to select fluids that meet the above criterion for a safe situation at the known surface temperatures.

However, if hot surfaces at temperatures above 800 °C may be present, the Manifold Ignition Test is not suitable to control the hazard and other, more appropriate, test procedures that have been designed specifically to address the hazard, should be used.

B.5 EN ISO 2592 - Flash Point – Cleveland Open Cup

NOTE When fire point or flash point test methods are used to collect information about the fire-resistance properties of a fluid, it is necessary to remember that these methods do not address the property of fire-resistance in any way, although they can give valuable information about the ignition of a fluid. It should also be remembered that results from flash point or fire point test methods are not in any way intrinsic chemical or physical properties of the inspected product, since these results depend to a large extent on the test apparatus, parameters and environmental conditions. Therefore, the results from these test methods should be interpreted with extreme care.

B.5.1 Test description

The ease with which vapours above a heated fluid become ignited is measured by the “flash point”. The flash point is the lowest temperature at which the application of a test flame directed over the surface of the fluid contained in a cup causes the vapour above the fluid to ignite. It is indirectly a measure of both the volatility of the fluid and the flammability of the volatiles contained in it. The Cleveland Open Cup flash point method contained in EN ISO 2592 may be used for the assessment of the relative hazard from combustible vapours arising as a result of excessive heating of a fluid.

B.5.2 Performance

For guidance, when measured by EN ISO 2592 the flash point of mineral oil falls within the range 180 °C to 220 °C.

The flash point cannot be determined for water-based fluids and is therefore not relevant to the control of this hazard for water-based fluids.

Annex C
(informative)

Examples of fire risk assessment procedures for hydraulic fluids

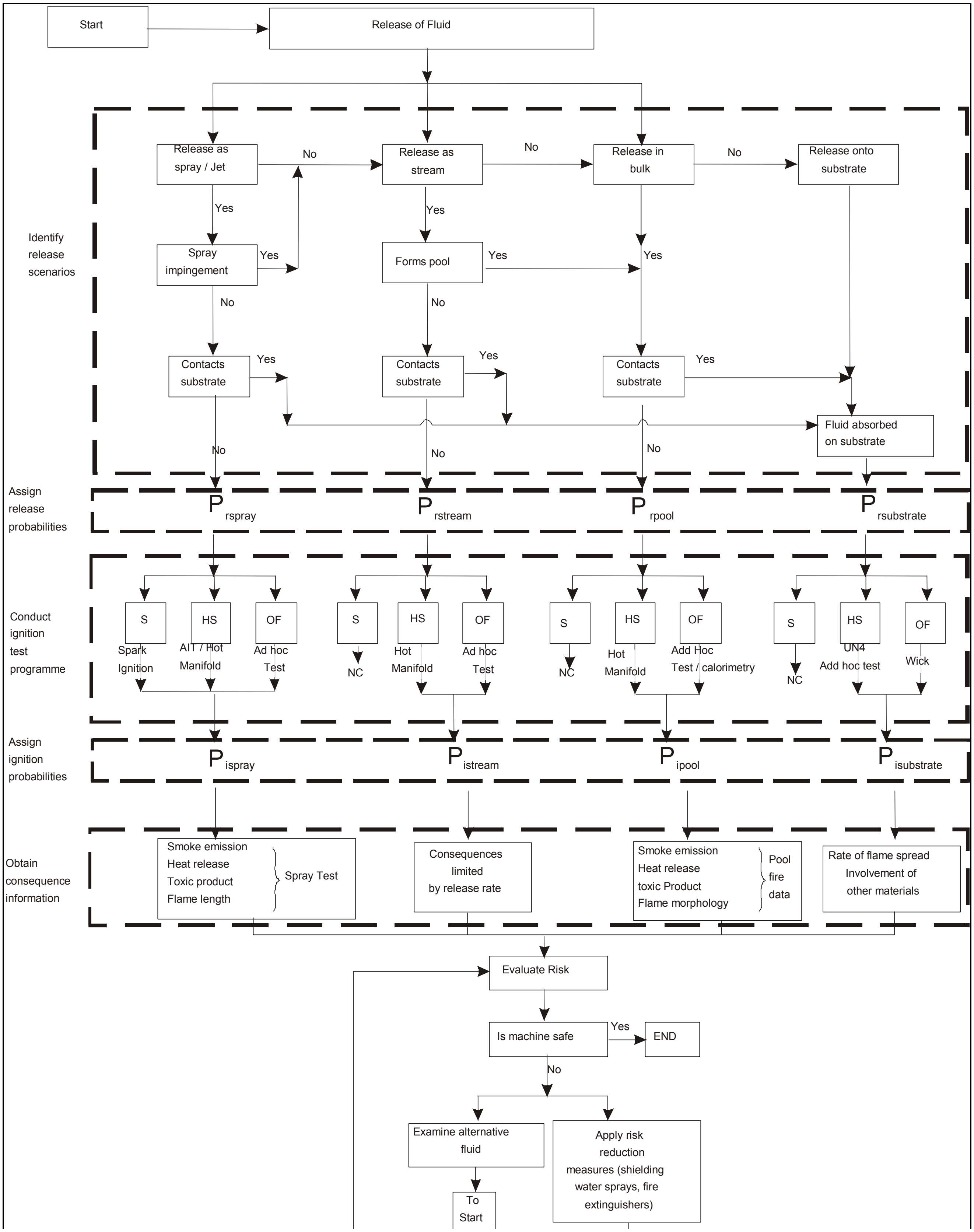
C.1 Introduction

This annex is concerned only with dangers from fire. It is in three parts. The first part sets out a procedure for the selection of a hydraulic fluid based on the performance of the fluid in specific tests in the form of a flowchart. The second and third parts give examples of both simple and complex risk assessment approaches, the latter dealing with a particular machine in a specific circumstance, which draws on information from a very wide variety of sources and which enables a comparison to be made of the effectiveness of a variety of fire protection measures.

NOTE In this annex the designation "p.a." is used to designate risk per year ('per annum').

C.2 Flowchart

The flowchart (Figure C.1) provides a generalised procedure for the selection of hydraulic fluids with respect to their fire properties only. It does not deal with health or environmental hazards.



KEY

S Spark
HS Hot Surface
OF Open Flame
NC Not Credible
P_r Release probability
P_i Ignition probability

Figure C.1 — Procedure to select hydraulic fluids

C.3 Simple Risk Assessment

In many cases a full risk assessment may not be justified. In this situation it may be appropriate to apply risk index methods, originally developed for building fires. In these methods a parameter variously described as a "risk score" or "Risk value", S, is computed according to the equation:

$$S = \sum w_i c_i \qquad \text{(C.1)}$$

where:

w_i is some weight of attribute i ;

c_i is a measure of the severity of the consequence for attribute i.

"Risk scores" are functions of a number of attributes chosen to characterise each situation based on fire scenarios or loss statistics and weights assigned to them possibly through an assessment of probabilities. In this case the possible accident scenarios may be chosen and w_i and r_i aligned with likelihood of occurrence and consequences of the scenario. In these schemes numerical values are introduced for w_i and c_i using normalised scales. Thus in this case the likelihood of occurrence might be assessed using a scale from 0 to 3 with 0 being not credible, 1 unlikely, 2 medium probability and 3 highly likely. Similarly combustion consequences could follow a similar scheme with 1 representing minimal consequences, 2 medium level effects and 3 severe consequences. The test results might then be used to define these categories.

A tentative classification is set out in Table C.1. This table has been derived using evidence from a number of fluid test programmes. It is put forward in tentative form and would require future examination should it be proposed for more widespread use. In most cases the limits on toxic product production have been omitted. For this hazard it might not be possible to identify a single toxic product which could be used as a measure across the spectrum of fluids in use since variations in fluid composition will determine the most hazardous combustion product produced. This may therefore be fluid dependent. Clearly also the proliferation of question marks indicates that further work is required to fill in gaps.

As an example we might consider the situation where we are comparing two potential fluids, say a polyglycolether (PGE) and a rape seed oil derivative in a particular end use situation. The situation suggests that the release could occur as a spray and at some stage be absorbed on to a substrate. The spray hazards are taken to comprise heat release and smoke production and the ignition sources present are hot surfaces at about 400 °C and sparks of unknown energy. For absorbed fluid the only hazard considered is the ability to propagate a flame.

For hot surfaces the rapeseed will probably not ignite since its hot manifold temperature is ~466 °C but a small factor might be included so that the weighting factor is 1. That for the PGE was found to be 396 °C and the ignition probability should be taken as one so the weight factor takes a value 3. The spark ignition energy for the rapeseed was found to be low (<1J) whereas that for the PGE was an order of magnitude higher. As a result the rapeseed and PGE should be graded 3 and 2 respectively for this aspect. Since the tests on thermal runaway suggest that both fluids would respond at such temperatures (onset of thermal runaway at 190 °C and 170 °C for the rapeseed and PGE respectively) a weight factor of 3 should be assigned to each fluid.

Table C.1 — Tentative sets of limits for use in a simplified risk assessment scheme

Information	Release	Hazard	Low	Medium	High
Ignition (related to w_i in (C.1))	Sprays	Spark ignition energy limits, J	E>50	1<E<50	E<1
		Hot surface temperature limits, °C	T>600	400<T<600	T<400
		Response to small open flame	Immediate ignition	Transient flame	Continuous flame
	Bulk fluid	Spark ignition energy limits, J	NC		
		Hot surface temperature limits, °C	T>600	400<T<600	T<400
		Response to small open flame	?	?	?
	Fluid on a substrate	Spark ignition energy limits, J	NC		
		Hot surface temperature limits, °C	T>200	100<T<200	T<100
		Response to small open flame	No ignition		Continuous burning
Consequences (related to c_i in (C.1))	Sprays	Heat release parameter limits, RI	RI>50	25<RI<50	RI<50
		Flame length parameter limits RL	RL<10	10<RL<50	RL>50
		Smoke production m^3 OD1 smoke g^{-1} $x10^3$	S<10	10<S<50	S>50
		Toxic product production ppm g^{-1}	?	?	?
	Bulk fluid	Heat release rate limits, kWm^{-2}	H<300	300<H<500	H>500
		Flame length limits, m	?	?	?
		Smoke production m^3 OD1 smoke g^{-1}	S<0.1	0.1<S<0.5	S>0.5
		Toxic product production ppm g^{-1}	?	?	?
	Fluid on a substrate	Heat release rate limits, kW	NC		
		Flame length limits, m	NC		
		Smoke production m^3 OD1 smoke g^{-1}	NC		
		Toxic product production ppm g^{-1}	NC		
		Flame spread rate	?	?	?
NOTE "NC" indicates a non-credible hazard and " ?" indicates limits which have yet to be developed					

For spray combustion consequences the gradings for heat release are 3 for the rapeseed and 2 for the PGE and for smoke production 2 and 3. Both fluids supported flame spread on a wick and since the rates were similar they should perhaps both score 3 on this aspect.

Table C.2 provides a method of visualising how the overall risk rating may be assigned using the PGE as an example.

Table C.2 — Matrix on overall risk rating

		Consequence		
		Heat release score 2	Smoke production score 3	Flame propagation score 3
Ignition potential	Hot surface ignition score = 3	6	9	-
	Spark ignition score = 2	4	6	-
	Spontaneous heating on substrate score = 3	-	-	9

Summing the scores suggests that the rapeseed has a slight advantage over the PGE for this application with totals of 29 for the rapeseed and 34 for the PGE respectively. The introduction of further operational factors in conjunction with the above may, however, alter the apparent merits of one fluid over another.

C.4 Quantified Risk Assessment

C.4.1 Introduction

Hydraulically-driven machinery, particularly that is used underground, can be fitted with a number of means to mitigate against the likelihood and effects of a fire. These may include water spray barriers, hand-held fire extinguishers or fire-resistant hydraulic fluids. The benefit provided by each of these may be compared by the use of quantified risk assessment (QRA). The following shows an example of this approach for a tunnel boring machine (TBM) highlighting where data shall be obtained from other sources and assumptions made.

C.4.2 The tunnel boring machine

C.4.2.1 Overview

The TBM in this particular example was 5,71 m diameter and 80 m long producing a pre-cast concrete lined bore of internal diameter 4,9 m. It comprised the following.

a) Circular cutting face the full diameter of the tunnel, driven by electric motors;

b) conveyor system for removal of spoil;

c) erector for the curved sections of pre-cast tunnel lining segments;

d) hydraulic jacks and rams to propel and steer the machine;

e) single track rail system to supply the machine with materials and remove the spoil;

f) ventilation supply to the front of the machine with face extract in overlap mode;

g) electrical power and control systems, supplied by an 11 kVA line reel;

h) emergency diesel generator to be used in the event of power failures.

Up to ten people could have been working on the TBM with others in the tunnel itself. The hydraulic power packs were approximately 17 m behind the cutting face. The maximum and normal operating pressures were 30 MPa and 20 MPa respectively. The maximum sizes of high pressure supply and low pressure return pipework were 50 mm and 100 mm. The fluid used was a polyolester with total inventory of 9 000 l.

The following leak locations from the hydraulic system were identified.

i) Hose failures including bursts and coupling leaks;

j) pipework failures;

k) joint leaks;

l) seal failures;

m) reservoir leaks.

The main areas of concern regarding fire were:

n) Tail seal grease unit;

o) hydraulic skid;

p) transformer and distribution switch gear;

q) emergency diesel generator.

C.4.2.2 Fire protection systems

Several fire protection systems were installed along the TBM and inside the tunnel including the following.

a) Hand held CO_2 and powder extinguishers;

b) fixed CO_2 systems on the diesel generator transformer, and locomotives;

c) water spray system along the full length of the walkway;

d) water spray barrier at the tail end to delay smoke spread along the tunnel;

e) flame detectors in the shield, close to the control cabin, hydraulic skid and power cabinets;

f) gas detectors near the end of the screw;

g) water main in the tunnel with couplings and fire hoses every 70 m and on the TBM.

The likelihood of extinguishing any fire depends on factors such as the nature of the release, i.e. spray or pool, and the prompt and efficient operation of the extinguishing system.

C.4.2.3 Other potential fire hazards

Fires on conveyor belting due to overheating rollers were considered to have only a low probability due to absence of combustible material such as coal dust, the small length of belting compared to that in a coal mine, and the fact that bearings were new and unworn.

C.4.3 Failure frequencies and release rates

C.4.3.1 Failure rates

Due to low usage and incident rates, records of hydraulic component failure rates for TBMs are not generally available. To provide suitable data, therefore, estimates of failure rates were obtained by comparison with an analogous machine used underground - in this case a coal shearer was used. Table C.3 gives relevant example Safety Reliability Service data for such a machine.

Table C.3 — Failure rates for hydraulic components

Component	Failure rate *per item-hour (calendar)*
Hose	$2{,}8 \times 10^{-5}$
Hose coupling	$1{,}1 \times 10^{-5}$
Control valve	$2{,}0 \times 10^{-6}$
Steel pipe (inc. couplings)	$2{,}9 \times 10^{-6}$
Oils seals	$2{,}8 \times 10^{-6}$

In this case modification of the coal shearer failure rates shall be made to allow their use for the TBM. First for the relative numbers of each component in the hydraulic system for which manufacturer information was obtained. Correction was also required for operating time: Based on a 5 day week and 24 hour working a correction factor of 5,1 was derived. Further corrections were made for pipe length and possibility of a rockfall. Hence:

Hose: ratio of length TBM/coal shearer hose = 0,84

Steel pipe: ratio of length TBM/coal shearer pipe = 0,84

Hose and steel pipe: fraction of failures not due to rockfall, etc. = 0,50

Applying these factors gives the component failure rates in Table C.4.

Table C.4 — Component Failure Rates

Component	Failure rate	Designation
Hoses	228×10^{-6}	A
Couplings	101×10^{-6}	B
Control valves	$71{,}4 \times 10^{-6}$	C
Steel pipe (including couplings	$21{,}7 \times 10^{-6}$	D
Oil seals	177×10^{-6}	E

C.4.3.2 Fluid releases

These failures result in different fluid releases. In general, plant / machinery experience was used to derive the range of possible pipe failures assumed to occur to the following scheme:

- Small (2 mm hole) 60 %
- Medium (5 mm hole) 35 %
- Large (full bore) 5 %

These proportions were applied universally to hoses, pipes and couplings. Further extension of this scheme was required to proceed. Thus half the small releases were assumed to occur as drips from low pressure parts of the system and half as sprays from a 2 mm diameter equivalent hole. Similarly half the medium releases were taken to occur as drips and sprays. For valve and seal releases 90 % were assumed drips and 10 % sprays from 2 mm holes.

The resulting overall release frequencies were therefore:

- Drips F(D) = (A+B+D) x 0,3 + (C+E) x 0,9 = 3,29 x 10^{-4} p.a.
- 2 mm spray F(2) = (A+B+D) x 0,3 + (C+E) x 0,1 = 1,31 x 10^{-4} p.a.
- 5 mm spray F(5) = (A+B+D) x 0,35 x 0,5 = 0,72 x 10^{-4} p.a.
- 5 mm non-spray F(N) = (A+B+D) x 0,35 x 0,5 = 0,72 x 10^{-4} p.a.
- Full bore F(F) = (A+B+D) x 0,05 = 0,21 x 10^{-4} p.a.

C.4.3.3 Release sizes

Drips were assumed to form a pool and thus no release size was derived. In this case the largest possible pool was set at 3 m^2 set from layout of bulkheads, floor partitions etc. For other releases the discharge rate may be estimated using standard methods so that the frequency and size of each release was:

Scenario	Release size	Frequency
Drip Pool	3 m^2	3,29 x 10^{-4} p.a. = F(D)
Spray from 2 mm hole	0,35 $kg.s^{-1}$ – 0,44 $kg.s^{-1}$	1,31 x 10^{-4} p.a. = F(2)
Spray from 5 mm hole	2,3 $kg.s^{-1}$ – 2,8 $kg.s^{-1}$	0,72 x 10^{-4} p.a. = F(5)
Non-spray from 5 mm hole	2,3 $kg.s^{-1}$ – 2,8 $kg.s^{-1}$	0,72 x 10^{-4} p.a. = F(N)
Full bore release (<5 mm)	2,8 $kg.s^{-1}$	0,21 x 10^{-4} p.a. = F(F)

C.4.4 Test data for hydraulic fluids

Some relevant test data were examined in detail to assess the implied fire resistance.

Data were available on hot surface ignition and persistence of burning of a spray. Such test data shall be regarded with caution due to their dependence on test conditions and it was therefore conservatively assumed that, with a spray directed at an ignition source, sustained combustion would result. It was also noted that tests on fluids of a similar generic type from other manufacturers showed that test results were strongly influenced by age/degree of fluid use.

C.4.5 Event probabilities and fire frequencies

C.4.5.1 General

Having established values for release frequencies and rates, it is then necessary to estimate the likelihood of an immediate or delayed ignition. The properties of the oil concerned indicate that it would not ignite readily, particularly if formed as a pool. A spray or mist is far easier to ignite. There are a number of stages between a release of oil and any resulting fire. These can be represented by a simple event tree shown in Figure C.2. This shows a number of possible outcomes, a to h, for a given release. These are described in Table C.5 which shows that for a specific release of frequency, F, the overall probabilities of explosion or fire are therefore:

F.P1.P4+F.(1-P1)(1-P2).P3.P5 (C.2)

F.P1(1-P4)(1-P6)+F.(1-P1)(1-P2).P3.(1-P5)(1-P7) (C.3)

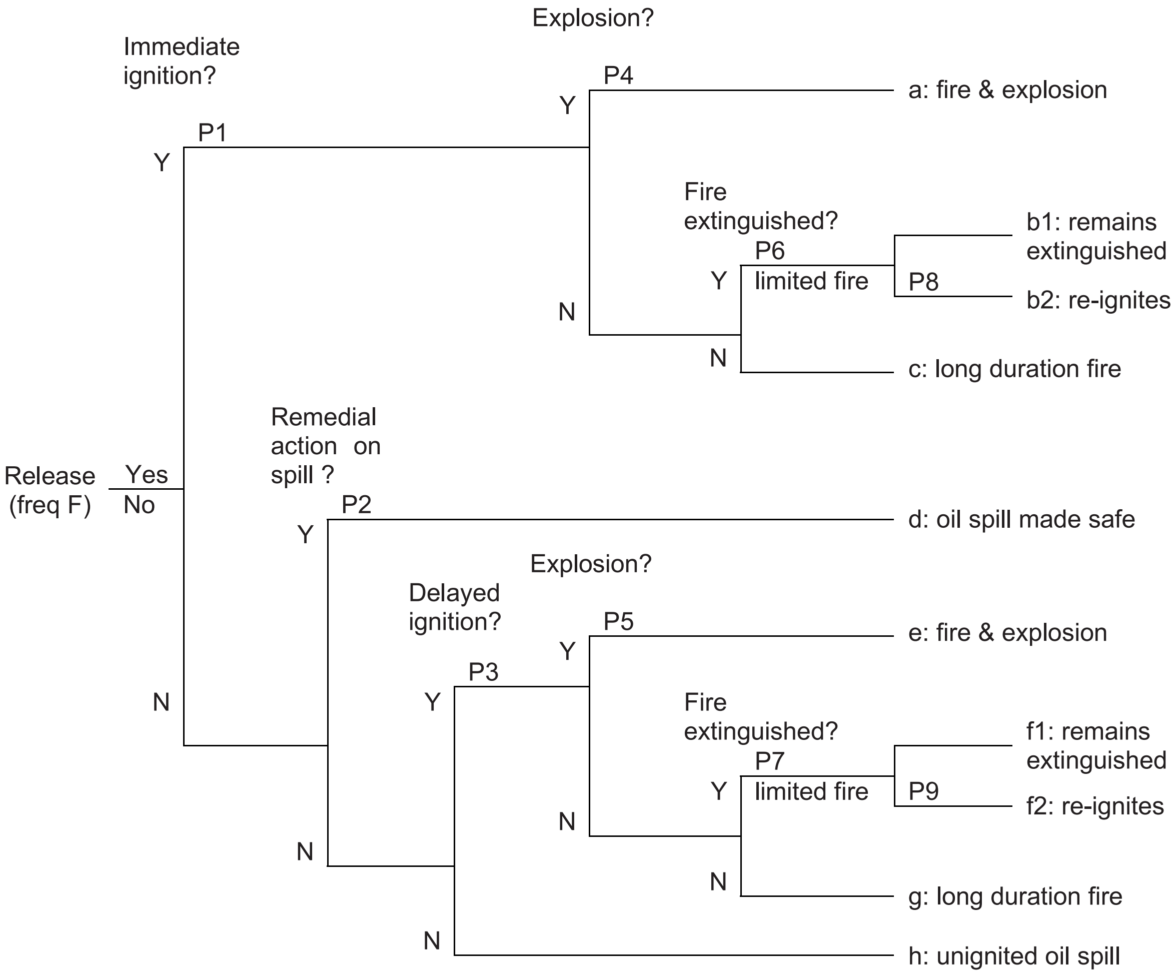


Figure C.2 — Event tree for probable fire and explosion scenarios modified to include the re-ignition of fires

C.4.5.2 Probabilities

The relative likelihood of these events depends on the probabilities P1 to P7 (see Figure C.2), which are related to the size and nature of the oil release and the environment into which it is released. The important features of the environment include:

— number and location of potential ignition sources;

— procedures for dealing with oil spills;

— fire fighting equipment provided;

— level of training and experience of the personnel.

Table C.5 — Range of outcomes for fires in event tree

	Event		Frequency	Comment
a	Fire and explosion		F x P1 x P4	Only possible for jet spray release which results in oil mist cloud
b1	Limited fire	fire remains extinguished	F x P1 x (1-P4) x P6	Consequences likely to be limited
b2	Limited fire	re-ignition and flash-fire	F x P1 x (1-P4) x P6 x P8	Potentially very serious consequences
c	Long-duration fire		F x P1 x (1-P4)(1-P6)	Consequences could extend hundreds of metres down tunnel
d	Oil spill made safe		-	-
e	Fire and explosion		F x (1-P1)(1-P2) x P3 x P5	As "a"
f1	Limited fire	fire remains extinguished	F x (1-P1)(1-P2) x P3 x (1-P5) x P7	As "b"
f2	Limited fire	re-ignition and flash-fire	F x (1-P1) (1-P2) x P3 x (1-P5) x P7 x P9	Potentially very serious consequences
g	Long-duration fire		F x (1-P1)(1-P2) x P3 x (1-P5) (1-P7)	As "c"
h	Unignited oil spill		-	-

Following consideration of these factors and particularly safety measures in place, estimates for the probabilities P1 to P9 were deduced.

C.4.5.3 Fire frequencies

Using the values of P1 to P9 in Equation (C.1) and Equation (C.2), together with the appropriate release frequency, gave the fire and explosion frequencies in Table C.6.

Table C.6 — Fire and explosion frequencies

Fire size	Frequency of fire	Numerical value
3 m^2 pool	F(D) x 5,5 x 10^{-5}	1,81 x 10^{-8}
0,35 – 0,44 $kg.s^{-1}$ release	F(2) x 0,001 6	2,10 x 10^{-7}
2,3 – 2,8 $kg.s^{-1}$ release	F(2) x 1,1x10^{-4} + F(5) x (1,1x10^{-4} + 0,001 6) + F(N) x 1,1x10^{-1} + F(F) x 1,1x10^{-4}	1,48 x 10^{-7}

The effects of an explosion would probably be outweighed by those of an ensuing large fire. Similarly the finite ventilation rate for the tunnel meant that scenarios with 5 mm and full bore failures were likely to result in similar consequences.

C.4.6 Consequence assessment

C.4.6.1 Fire

The potential consequences of a fire on the TBM were calculated assuming that releases of fluid when ignited gave a range of heat outputs. The hazards from a fire were taken to be injury from the heat generated or from exposure to toxic combustion products. To quantify these hazards relevant details such as the tunnel dimensions, the fluid heat of combustion and density were input to a computer programme for the calculation of TBM fire consequences in blind head tunnels, specifically to calculate smoke temperature and velocity at various points, the personnel thermal dose and toxic exposure, given an initial location, reaction time and escape velocity. The effects of toxic exposure are difficult to quantify so it was assumed that those exposed to smoke for more than a few minutes were unable to escape. The mitigating effects of a TBM water spray barrier were estimated using a separate programme.

C.4.6.2 Explosion

Under certain circumstances ignition of an oil mist can give rise to an explosion. Such explosions have occurred in the crank-cases of large engines with pre-heated oil. They are unlikely in a tunnel and their consequences are outweighed by those of any subsequent fire.

C.4.6.3 Results

The programme was applied to each fire scenarios, for both typical 20 MPa and maximum 30 MPa operating pressures. In all runs the reaction time was assumed to be 10 s and escape velocity 1 ms^{-1}. The distance to the tunnel exit was 600 m. For comparison, the mitigation provided by a water spray barrier were calculated for the same fire sizes. Here the reduction in temperature from mixing effects induced by the water spray were obtained using the relation:

$$\Delta T = \left(\frac{16H}{\pi \rho C_p D^2 (g\alpha)^{1/2}} \right)^{2/3} \qquad \text{(C.4)}$$

Where:

ΔT is the temperature reduction (°C),

H is the heat flux (W/m^2),

ρ is the density of hot air at 1 000 °C (kg/m^3),

C_p is the specific heat of hot air (J/kg),

D is the tunnel diameter (m),

g is the acceleration due to gravity (m/s^2)

α is 1/temperature (degrees C^{-1}).

In determining the effects of a water spray, a generalised reduction was calculated along the length of the TBM as, in this case, two spray systems were installed. Velocity and temperature reductions generated by the water spray reduced both thermal dose to and toxic exposure of personnel. Close to the fire, the calculated effects of the water spray were to increase the time taken to reach the toxic threshold through smoke inhalation. Increases in times to incapacitation ranged from a few to approximately 140 %. At greater distances along the tunnel, or for smaller fires, the thermal dose for those escaping was lower.

C.4.7 Numerical risks - results

The results of a risk assessment are usually presented in terms of individual and societal risk.

The risk of people receiving a significant thermal dose or toxic exposure as a result of a fire involving hydraulic oil, or other combustible material on the TBM is obtained by combining the frequencies of fires occurring with calculations of the consequences. Here the significant thermal and toxic exposures were taken to be 1 000 $(kWm^{-2})^{4/3}$ and 180 s respectively.

For an initial position 10 m from the fire, Table C.6 indicates that a significant thermal dose would be received for both the 2 mm and 5 mm spray releases, but not the 3 m^2 pool. The overall risk was therefore the sum of frequencies for the 2 mm and 5 mm jet fire scenarios given in Table C.6. Thus

Risk at 10 m = $(2{,}1 \times 10^{-7} + 1{,}48 \times 10^{-7})$/h = $3{,}58 \times 10^{-7}$ per hour

Table C.7 — Tunnel fire consequences - with water spray barriers

Fire type	Hazard TD = thermal dose *$(kw.m^{-2})^{4/3}.s$* TE = toxic exposure *s*	Initial position of person from fire *m*					
		10	30	100	150	300	500
3 m^2 pool	TD	0 [a]	0 [a]	0 [a]	0 [a]	0 [a]	0 [a]
	TE	0	0	0	0	0	0
0,35 $kg.s^{-1}$ (20 Mpa)	TD	>8 000	0 [a]	0 [a]	0 [a]	0 [a]	0 [a]
	TE	0 [b]	0	0	0	0	0
0,44 $kg.s^{-1}$ (30 MPa)	TD	>8 000	0 [a]	0 [a]	0 [a]	0 [a]	0 [a]
	TE	0 [b]	0	0	0	0	0
2,3 $kg.s^{-1}$ (20 MPa)	TD	>8 000	>8 000	> 8 000	5,179	681	0 [a]
	TE	0 [b]	17 s	81 s	>180 s	>180	0
2,8 $kg.s^{-1}$ (30 MPa)	TD	>8 000	> 8 000	> 8 000	4,787	716	0
	TE	0 [b]	26 s	115 s	181 s	>180	0

[a] individual escapes without receiving toxic exposure or thermal dose.

[b] individual engulfed in flame.

At a distance of 30 m, 100 m, 150 m and 300 m from the fire only the 2,3 $kg.s^{-1}$ or 2,8 $kg.s^{-1}$ spray releases produced thermal and toxic doses in excess of the set criteria. The risk at these distances was therefore $1{,}48 \times 10^{-7}$ per hour. With the use of spray barriers neither the thermal nor the toxic criteria were exceeded at 500 m, so the risk at this distance was zero. Table C.8 gives the risk computed for each initial distance.

Table C.8 — Risk values for exposure to fire at specified distances along tunnel

	Initial distance from fire *m*					
	10	30	100	150	300	500
Risk per hour	$3,58 \times 10^{-7}$	$1,48 \times 10^{-7}$	$1,48 \times 10^{-7}$	$1,48 \times 10^{-7}$	$1,48 \times 10^{-7}$	0
Risk per year (8 000 hours)	0,002 9	0,001 2	0,001 2	0,001 2	0,001 2	0

The risks in Table C.8 refer to 24 hour operation. An individual would not be exposed to this continuous risk. Assuming a 4 shift system, a correction factor of 0,25 shall be applied to the figures in Table C.8 The maximum individual risk was therefore (0,002 9)/4 p.a. or $7,3 \times 10^{-4}$ p.a. This assessment was aimed at calculating the frequency at which specified toxic and thermal criteria were exceeded rather than for fatal or serious injury.

C.4.8 Conclusions

The results of this risk assessment showed that the effects of a fire or explosion could cause fatalities several hundred metres back from the driving face. The maximum risk to an individual of fatal injury (at a position 10 m from the release) was $7,3 \times 10^{-4}$ p.a., or 1 in 1 340. The risk decreased with initial distance from the release but even at 300 m the risk was still 3×10^{-4} p.a. or 1 in 3 333. The societal risk of 10 or more fatalities was $1,2 \times 10^{-3}$ p.a., or 1 in 833.

It is recognised that there may be uncertainties in the data throughout this study, particularly those used to determine the relative number of items on the TBM and coal shearer. In such a study with large uncertainty in input data it is always wise to conduct a sensitivity study.

The use of a fire-resistant hydraulic fluid could be a factor in ensuring safety and the provision of a water spray system along the walkway and at the end of the TBM will have a significant effect on smoke, temperatures and propagation rates thus considerably assisting evacuation.

Apart from the possibility of fires involving the hydraulic fluid, the study identified a number of other areas of potential concern:

- emergency diesel generator;
- tail-seal grease;
- conveyor belting;
- electrical equipment, particularly the transformer;
- diesel locomotives.

Annex D
(informative)

Tests suitable for monitoring the condition of hydraulic fluids in service

D.1 General

The following tests are suitable for carrying out on samples of fluid drawn from service. It is important that the samples should be representative of the bulk fluid. The provision of properly designed sampling points and the establishment of procedures for sampling is advisable. More detailed information on sampling is found in EN ISO 3170 [19]. These tests do not necessarily provide direct measures of the primary properties of a fluid, such as fire resistance, but provide measures of fluid condition that may be related to the primary properties. Advice should be sought from fluid manufacturers/suppliers on appropriate tests to monitor the relevant properties.

D.2 Viscosity

Viscosity grades in ISO 3448 have a tolerance of ± 10 % of the nominal grade viscosity. The viscosity should therefore remain within ± 10 % of the initial viscosity.

D.3 Neutralisation number or pH value

Changes to the neutralisation number (non-aqueous fluids) or pH value (water-based products) can indicate chemical breakdown of the hydraulic fluid. The change in neutralisation number or pH value that is tolerable should be discussed with the fluid supplier.

D.4 Water content

For water-containing fluids it is the water content that provides fire resistance. It is important, therefore, that the water content should be maintained. Precise allowable levels should be discussed with the fluid supplier.

For fluids that do not derive their fire resistance from their water content the presence of water can be deleterious to hydrolytic stability and to lubricating properties. The water content should be kept as low as possible, and allowable limits discussed with the supplier.

D.5 Insolubles content

The presence of insolubles may not affect the fire resistance, but will affect the reliability of the hydraulic system. The level of insolubles that is tolerable will depend on the precise nature of the hydraulic system.

D.6 Microbial infestation

Microbial infestations caused by bacteria and fungi can be a particular problem with water-containing fluids. They may result in the breakdown of emulsions and blockage of filters and pipes. The precise level of organisms that is tolerable will depend on the type of fluid and the nature of the hydraulic system, and should be discussed with the fluid supplier.

Test equipment that may be used on site is available to carry out the above tests.

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