methods of prevention, detection and control of spillages in european oil pipelines

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ABSTRACT

This report gives information on the measures which are used to ensure safe operation of industry pipelines in Western Europe related to the causes of spillages. The result of the application of these measures has been a very low level of spillage over the 25 years that CONCAWE has collected statistics.

KEYWORDS

Corrosion, integrity, leaks, oil industry, pipeline integrity management, pipelines, safety, spillages

CONTENTS

SUMMARY

This report reviews the causes of spillage from operating cross-country oil pipelines and discusses the current practice in spillage prevention, detection and control. Data on spillages is recorded by CONCAWE and this knowledge assists in the continuous efforts to improve on performance and minimise the effects on the environment. Performance data for the past twenty-five years shows that the rate of spillage has been extremely low with a net spillage * of less than 0.0002% (one five-thousandth of a per cent) of the total volume transported. The total combined length of the operating pipelines was approximately 30 000 km in 1996.

Spillages are prevented by competent design, careful construction, rigorous inspection and efficient operation. Monitoring of the pipeline provides the information necessary to satisfactorily maintain the system and to allow a reaction to deviations from the norm. Various techniques are available to prevent spillages occurring, and if they do, to detect, locate and thus minimise the volume spilled. In case of an emergency, contingency plans and training of operators aim at quick spillage control and at minimising the impact on the environment.

The oil industry applies considerable effort to provide a safe and efficient pipeline transport service, whose performance record ranks amongst the best. Efforts will continue to be exerted to maintain and further improve on the high standards already obtained.

This report is published to inform a wider audience of the measures taken to achieve this result.

(Note: The first occurrence of a word defined in the Glossary is indicated with *).

1. INTRODUCTION

In 1987, CONCAWE[1] first published this report describing the preventative measures taken and the methods used to detect spillage from cross-country oil pipelines, together with the emergency procedures to be implemented in the event of an incident. For the purposes of CONCAWE studies, a cross-country oil pipeline is defined as one which runs between two sites crossing a significant length of land (at least two kilometres) and an incident is one where over 1 m^3 of oil is spilled.

Since that time, there have been a number of developments in pipeline integrity management. Also, a number of governments are making changes to their national legislation on pipelines and the EU is considering a directive to control the major accident hazards of pipelines. CONCAWE’s Oil Pipelines Management Group therefore decided that it was an appropriate time to update this report.

The prevention methods discussed are not all-encompassing nor are they necessarily applicable to every pipeline. The factors such as product transported, pipeline size, length and type of operation are considered to determine the most appropriate application of spill prevention methods. The requirements for a pipeline are determined during the design phase by the pipeline owner(s) or operator, and must meet as a minimum all regulatory authority requirements. A well designed pipeline, fit for the purpose of its specified duty and compatible with the environment it passes through, provides the basis for an efficient and safe system.

Sophisticated methods are increasingly being used to support more traditional methods for ensuring the integrity of the pipeline during all phases of a pipeline's life cycle, i.e. design, construction, operation, and eventual termination of oil transport service. Monitoring techniques combined with a high standard of pipeline protection, can only help to increase public confidence in pipelines as the safest means of transporting oil and associated products over long distances. Pipelines have established a reputation for being among the safest, and having the lowest impact on the environment of the various methods for transporting oil products.

The pipeline operators, with the Government institutions, recognise the need to maintain high safety standards and minimise the risks * to the environment. To this end this report will illustrate the efforts being taken to minimise these risks. As a result, over the last twenty-five years the CONCAWE data show that the total net spillage as a percentage of the combined total throughput was less than 0.0002%.

CONCAWE has collected information on the performance of oil industry cross-country pipelines in Western Europe for many years. This data is published in a series of annual reports, the latest of which was published in 1997 for the 1996 statistics.[2] As the data set now covers some 25 years, the opportunity has been taken to publish additional data on trends in performance and correlations between types of pipelines and failures etc., which is available in a complementary CONCAWE report.[3] As there are so few pipeline incidents per year, a long period of records is required to obtain a large enough database to give any statistical significance.

The gathering of this data via CONCAWE has provided valuable lessons in the efforts to minimise the spillage of oil products from pipelines.

*(Note: The first occurrence of a word defined in the Glossary is indicated with *).*

2. OIL INDUSTRY PIPELINES

2.1. EXTENT OF NETWORK

For the purposes of CONCAWE studies, a cross-country oil pipeline is defined as one which runs between two sites crossing a significant length of land (at least two kilometres) between two sites. It does not therefore include short pipelines connecting two parts of a divided site or two closely neighbouring sites. Such lines are properly considered as part of the sites in question. The term ‘pipeline’ includes intermediate pump stations, valve stations, pigging facilities and any associated tankage. Pump stations at the start of the line may or may not be included depending on their relationship with the originating site. Normally, the reception facilities apart from the pig* receivers will not be considered as part of the line.

The network currently included in the CONCAWE study comprises approximately 31 000 km of pipeline. Of this, some 10 000 km comprises ‘non-commercially owned pipelines’ which have only been included in the CONCAWE statistical database for the last six years. The major routes are shown in the map in the CONCAWE reports on “performance of cross-country oil pipelines in western Europe - statistical summary of reported spillages”.[2] The database is believed to contain the majority of oil industry pipelines currently operating in Western Europe although some minor short lines may not be included. In particular, coverage of short crude oil gathering lines in on-shore oilfields is not complete. Offshore pipelines are not included in the study, but where crude oil lines from offshore fields run onshore for a significant distance, the onshore sections are included. Of the total length of pipelines, some 11 000 km are 16 inch in diameter or over.

2.2. MATERIALS TRANSPORTED

The materials transported by the pipelines in the CONCAWE study fall into five main categories:

Stabilised Crude Oil is crude oil from which the majority of the gas has been removed so that a liquid stable at ambient temperatures results. Most of the crude oil transported by pipeline in Europe comes into this category, and for the most part, the lines included in this category transport crude oil from ports to refineries.

Unstabilised Crude Oil is crude oil still containing a significant proportion of hydrocarbon gases. It has to be kept under pressure as otherwise large volumes of gas are evolved. There is one major pipeline in this category carrying partially stabilised North Sea crude in Scotland.

White Oils are gasoline, kerosene (particularly jet fuel) and gas oils (diesel and heating oils).

Black Oils are heavy fuel oils, in the main the pipelines carrying black oils are comparatively short and supply major combustion plants such as power stations and steel works. In some cases, the fuel oils have to be heated before pumping to keep them liquid. Pipelines carrying heated fuel oils comprise a sub-set within the CONCAWE statistics.

LPG is propane and butane. The only lines in this category in the CONCAWE database are some short lines to jetties and loading terminals.

2.3. QUANTITIES OF MATERIALS TRANSPORTED

In 1996, the total volume of oil transported through pipelines in the CONCAWE database was 655 million m^3. The combined traffic volume was 119 m^3 x km x 10^9; *ie* the average length of journey was *ca*. 180km.

3. CAUSES OF SPILLAGES

In considering how best to avoid pipeline spillages, it is of interest to investigate what are the main causes of failure to be guarded against. For its annual reports,[1] CONCAWE collects data from the operator after each incident has been carefully analysed in order to inform other interested parties of the reasons behind the incident. This information allows others to benefit and helps to prevent their recurrence.

The causes of spillage are divided by CONCAWE into five main categories:

- mechanical failure;
- operational failure;
- corrosion;
- natural hazard *; and
- third party activity.

They are defined in **Sections 3.1 to 3.5**.

In the previous report,[1] covering fifteen years, it was reported that the greatest number of spillages was due to corrosion, but the greatest loss of product was caused by third party activity. This was because with corrosion, the initial hole is usually small, and the failure is normally discovered before it grows enough for a large spillage to develop. The quantities lost through spillage caused by corrosion are therefore usually small. Conversely, third party damage is usually by impact leading to larger ruptures which consequently result in larger losses before the pipeline can be shut down.

As can be seen from **Table 1** which summarises the reported causes of spillages from West European pipelines between 1971 and 1995, over this period, third party damage was responsible for both the largest number and the greatest volume of spillage.

Table 1 Causes of Pipeline Failure over 25 years (1971 - 1995)

Cause	Cause of incidents by Number	Percentage of Net Volume Spilled	Percentage of Gross Volume Spilled
Mechanical Failure	25%	30%	35%
Operational Failure	7%	3%	3%
Corrosion	30%	14%	19%
Natural Hazard	4%	4%	4%
Third Party	33%	49%	39%

More information on the relationships between cause and effect of pipeline spillages can be obtained from the accumulated CONCAWE statistics. This subject is covered in the complementary report.[3]

3.1. MECHANICAL FAILURE

Mechanical failures are ruptures and fissures that occur when stresses in the system exceed the allowable stress. They can be caused by poor material quality or faulty construction.

Manufacturing defects can occur in the pipe or fittings, e.g. in the pipe wall or in the longitudinal weld. Poor construction techniques can generate high residual stress levels in the pipeline prior to commissioning. For example, the forming of pipe bends, welding techniques and the handling of materials can all lead to unacceptable construction practices if not carried out according to the specification of the work.

Mechanical failure represents about 25% of the number of spillage incidents and about 30% of the net volume spilled over the whole twenty-five year period.

Section 5.1 describes the approach to pipeline design and the measures taken to prevent mechanical failure and **Sections 5.2** and **5.3** describe measures taken during construction and commissioning.

3.2. OPERATIONAL FAILURE

Operational failures can be due to overpressure or malfunction of systems such as pressure relief or control devices. They are also caused by human error such as failing to observe the correct operating instructions. However, the Industry has gained great experience of operating pipelines and the incidence of spillages caused by operational error is very low at 7% of incidents in the twenty-five year data.

Section 5.4 describes the general approach to pipeline operations.

3.3. CORROSION

In the past, corrosion has been the most common cause of spillage although the quantities involved are usually small. **Table 1** shows that over the whole twenty-five years, corrosion was responsible for only 14% of the net volume losses, but an average of 30% of all spillage incidents.

Pipelines are subject to two types of corrosion - internal and external. Details of the measures taken to prevent both types of corrosion are given in **Section 5.1.5**.

Crude oils and oil products can give rise to internal corrosion when corrosive products are present usually in combination with water. Corrosion can also occur when pipelines are not in use.

External corrosion occurs either because the pipeline coating * is found to be inadequate and/or the cathodic protection * is inefficient.

The majority of the incidents of spillages due to corrosion reported by CONCAWE are caused by external corrosion.

3.4. NATURAL HAZARD

Natural hazards are phenomena such as landslides, flooding, ground subsidence and earthquakes. **Section 5.1.2** describes how areas susceptible to these phenomena are avoided where possible at the route planning stage. Where such areas cannot be avoided the design of the pipeline takes account of these anticipated hazards (**Section 5.1.6**).

These routing and design policies have resulted in a very low incidence of failure due to natural hazards of only 4% of the incidents in the 25 year period.

3.5. THIRD PARTY ACTIVITY

Third party activity was responsible for about 30% of the number of incidents in the 25 year period, but for 49% (by net volume spilled) of all spillages.

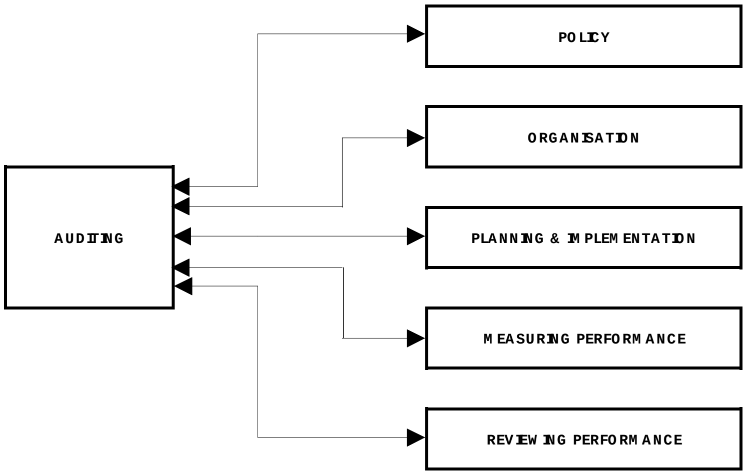
The majority of these spillages are caused by accidental damage inflicted after construction of the pipeline by third party excavation in the vicinity of the pipeline. Surveillance and inspection procedures are designed to minimise the amount of damage caused by third parties, and these are described in **Section 5.6.**

A small number of spillages (<1%) are caused by deliberate criminal attempts to rob the pipeline of its product, or to cause nuisance.

4. PIPELINE INTEGRITY MANAGEMENT SYSTEMS

The oil industry regards pipelines as one component of its overall business and assets. It therefore applies similar safety management systems [4] as to all its other activities. The member companies of CONCAWE have in general developed systems similar to that shown in **Figure 1** whereby there is feed back at all stages to ensure continuous improvement.

Figure 1 Outline of a Safety Management System



Such systems have been developed to improve the safety performance of companies partly from community and legislative pressure, partly from their desire to protect their work-force and neighbours, but not least for business reasons. Accidents are costly and can result in fines, lack of customer confidence, difficulties in retaining the licence to operate and in particular financial losses from an interruption to business.

A particular safety management system has evolved for pipelines and is referred to as a Pipeline Integrity Management System or PIMS. In this section, the general principles are described. The detailed procedures used to prevent, detect and control spillages are presented in **Sections 5, 6 and 7.**

4.1. TECHNICAL INTEGRITY

The concept of Technical Integrity was first introduced to the European Petrochemical industry as a recommendation in the report of the Court of Inquiry into the Flixborough accident in the UK in 1974:

> "Measures must be taken to ensure that the Technical Integrity of any plant is not violated as a result of subsequent modification."

Initially, integrity was supposed to refer to the elimination of danger to people, the environment and assets but with many this has been extended to include a "fit for purpose" condition to allow the facility to fulfil its intended function. Consequently a current definition of integrity would refer to the Technical Integrity of a facility, which is achieved when, under specified operating conditions, there is no unacceptable risk of failure endangering safety of personnel, environment, asset value or facility availability. Risk of failure is defined as the product of failure probability and failure consequence.

Furthermore, Technical Integrity is emphasised as being a common responsibility of both the Engineering and Operations functions with Engineering responsible for defining what constitutes Technical Integrity and Operations responsible for the safeguarding of Technical Integrity

Firstly, Technical Integrity needs to be created. This is achieved during the project phase. The core requirements are competent design (based upon a well understood and formally approved operational philosophy) and assurance of the quality of the materials, equipment and construction activities. This needs to be carried out in line with an agreed set of standards.

Secondly, Technical Integrity needs to be safeguarded. Keys to this are effective and controlled procedures to ensure adequate maintenance and safe operating practices. These must include a thorough maintenance planning process to ensure that necessary actions are identified and implemented in a timely manner, work execution procedures to minimise induced hazards, contingency planning to contain any potentially hazardous occurrence and staff training to ensure an appropriate skill profile.

Technical Integrity is equated to the degree of confidence in the facility withstanding all design-accidental-events. Clearly, this does not equate to total confidence, since the remote possibility of the "thousand year storm, or the meteorite collision", defence against which is not provided by design, still exists.

Any deficiencies in the project phase will result in a shortfall in the desired level of integrity. However, in view of the many controls in place at the time of project handover, the shortfall is usually small at this point. After this, adequate management control is essential, otherwise there will be a drift away from the desired state of resilience to accidental events considered in the design phase.

4.2. MANAGEMENT CONTROLS

Operator errors are normally not the main cause of the adverse trends as in most cases these will be quickly noted and eliminated. Rather such trends are a result of evolutionary divergence of actual practice from authorised procedures, introduction of inadequately trained personnel and, under day to day pressure, the piecemeal and unrecognised neglect of appropriate operating practices (including excursions outside design operating conditions) and mandatory maintenance.

Management controls, including procedures necessary to ensure an effective information flow, are essential to counterbalance threats to Technical Integrity. Such controls should include change control and deviation monitoring procedures.

Technical reviews and audits may result in listings of remedial actions, the implementation of which will ideally restore Technical Integrity. Where effective formal systems are in place the shortfall should be minimal.

Operators have recognised the need for a more proactive approach to identify areas of potential exposure and have developed Pipeline Integrity Management Systems (PIMS). A comprehensive set of controls, encompassing all integrity management aspects, should be in place. The key elements for such a PIMS can be listed as follows:-

- Clear objectives and policies, inclusive of acceptable risk levels and an indication of priorities
- A suitable organisation with clear definitions of asset ownership and related responsibilities and competent and adequately trained staff
- Adequate standards and procedures, inclusive of deviation control
- Performance monitoring and suitable audit/review procedures.

Objectives and Policies of course have to be compatible with other corporate objectives. Specifically though for pipelines, identification of unacceptable risks, desired system availability and clear statements with regard to production priorities vis-à-vis maintenance requirements, are a must to avoid having to rely on ad-hoc decision making in the field, with all the related consequences for the Technical Integrity of the system.

For each pipeline, or group of pipelines, the asset holder is identified and the delegated responsibilities in relation to the PIMS for each life cycle phase defined. Particular attention is paid to the interfaces between the various life cycle phases. where different organisational parties carry responsibilities with regard to pipeline integrity.

PIMS cannot be successfully implemented without the full cooperation of all staff involved. It is therefore important that the staff responsible for executing critical activities related to pipeline integrity are fully involved in setting up a PIMS and are motivated in following the requirements once laid down in such a system. Staff numbers, skills and experience to comply with all the requirements specified in the PIMS need to be adequate. Training courses, covering the various technical aspects related to the creation and safeguarding of pipeline integrity must be provided by the owner/operator

Relevant expertise areas for the critical activities in a PIMS are:

- pipeline engineering;
- process technology;
- materials and corrosion engineering;
- operation and maintenance;
- telecommunication;
- instrumentation; etc

Materials and corrosion specialists play an important role in pipeline integrity, both in the design and construction phases and in the operations phase.

International codes supplemented by owner/operator standards addenda form the basis of design, construction and operation of pipelines. To cover comprehensively the essential aspects of a PIMS, however, these are further supplemented by written procedures and practices that address the control of each designated critical activity in the PIMS process. The procedures and practices cover the creation of integrity during the design and construction phase, the safeguarding and monitoring of integrity during the operations phase as well as the safeguarding of the environment following final abandonment. *

A change control procedure is vital, whereby any changes in the asset design or operational changes that would impact on the design are identified and subject to a formal review/approval process.

Complete and accessible documentation an essential and data management systems are required to efficiently handle the various forms of pipeline data so that relevant information is not lost and is readily available. A comprehensive corrosion management database is required which will contain information required for management of pipeline integrity during the operational phase.

A ‘live' document is required defining statutory requirements, the pipeline's planned throughput profile and availability, operating envelope, perceived risks, inspection and maintenance requirements over its entire planned lifetime.

Handover documentation after construction at the start of operations should be comprehensive, but also transparent so that essential requirements to safeguard integrity are clearly understood.

4.3. PERFORMANCE MONITORING

Performance monitoring of PIMS activities is essential in order to identify shortcomings and make corrections. The absence of a failure in itself does not imply that technical integrity is being achieved. Quantification of performance allows trends to be identified and the effectiveness of corrections to be measured. Quantified performance indicators could include:

- Failures,
- Cathodic protection outages,
- Corrosion rates,
- Departures from design operating conditions
- Third party impacts.

Where critical changes can gradually occur in operating conditions, it is recommended that the pipeline operator should formally review and revalidate the key operating parameters at regular intervals to prevent, or correct, unnoticed excursions from the specified operating envelope.

Assessment of risk in terms of pipeline failure probability and potential consequences in terms of safety, environment and direct costs of the company, can also be an effective tool in gauging the effectiveness of integrity related activities and optimising the performance of pipelines.

Review of the PIMS process itself should be included in the owner/operator audit and review programmes to identify possible improvements.

4.4. RISK ASSESSMENT

A comprehensive Quantified Risk Assessment (QRA) study is sometimes executed for the design and route selection of a pipeline carrying a specifically hazardous fluid through a sensitive and/or populated area. For ranking pipelines on the basis of risk and assessing the potential for risk reduction it is not necessary to carry out an expensive QRA study to determine absolute risk levels.

Simplified methods for pipeline risk ranking have been developed by different owner/operator companies as a tool for priority setting. These simplified risk ranking methods can provide consistency of use for a variety of fluids and many different types of locations. Other more semi-quantitative risk assessment methods have also been developed. The main objective of the methodology is to semi-quantitatively assess failure risk of pipelines, specifically to compare different options and conditions. For instance, the effect of changing various parameters during the pipeline design phase can be assessed in a quantitative and systematic way. In the operational phase such tools can be used to evaluate the effect of various operational activities on the risk levels, including changes in the operating envelope or external pipeline conditions, such as increasing population densities.

Risk can be minimised by either reducing the probability of failure or by reducing the consequences of failure. The probability of failure by external impact can be reduced by applying greater wall thickness and / or concrete coatings *, routing away from high risk areas, increasing the depth of burial and regular line surveillance. The probability of mechanical failure can be reduced by adequate materials, construction specifications and inspection during line pipe manufacturing and construction (e.g. 100% radiographic testing of welds). The probability of failure by corrosion can be reduced by applying greater wall thickness, improved coating and Cathodic Protection systems, product treatment and / or inhibition and regular inspections.

The consequences of failure can be reduced by pipeline routing, installing isolation valves with automatic or remote operation, and implementing leak detection and emergency response systems.

The integrity of the pipeline during its lifetime needs to be maintained by means of condition monitoring, fitness for purpose analysis and implementation of remedial actions and improvements where necessary. The condition monitoring programme should be defined on the basis of the anticipated degradation mechanics. Condition monitoring can involve line surveillance, coating and cathodic protection surveys, fluid corrosivity assessment with probes, coupons and fluid assessment and intelligence pig * inspection.

5. PREVENTION OF SPILLAGES

5.1. DESIGN

5.1.1. Introduction

Detailed studies of the pipeline route, design and location of associated equipment are carried out to eliminate causes of failure and to minimise the effects of pollution in the case of spillage. Pipeline design is regulated by strict national and international standards and specifications which are subject to continuous review and updating.

It is important that the initial design studies are thorough and that all foreseeable problems are reduced to an acceptable level during the design process. Studies are undertaken at this stage into the impact of the pipeline on the environment and the potential hazards that may be introduced.

The pipeline route and the locations of the pumping and valve stations are defined for the fluid to be transported and the topographical features where the equipment is to be installed.

The final design will aim to provide the best balance between plant, owners' requirements and the environment.

5.1.2. Pipeline Route

The choice of pipeline route is an important factor in ensuring the safety of the public, protection of the environment and integrity of the pipeline itself.

The design criteria for obtaining the most acceptable route are:

- select the optimum route feasible taking into account existing environmental, technical, and economic constraints;
- avoid or minimise the crossing lengths of areas of special geological or geographical conditions which may involve hazards;
- avoid or minimise the crossing lengths of areas where failure may result in substantial ecological damage.

Soil studies, topographical surveys and geological information are assessed to obtain technical solutions for crossing all obstacles, such as difficult terrain, roads, rivers, railways, etc. Special attention is given to the design of crossing important rivers and stretches of water. Underground routes are usually preferred to above ground routes where possible.

Hazard assessments and environmental studies which assess the effects of, for example, noise, pollution and accidents on the local population, are reviewed in more detail as the system design develops.

Inevitably some degree of compromise between these various criteria may be required with the aim of reducing the risks to acceptable levels using additional technical measures wher necessary.

5.1.3. Mechanical Design

The mechanical integrity of the pipeline is assessed by evaluating the stresses, pressures and external loads that could be experienced by the pipeline. Different operating modes are considered by varying the conditions such as flow and pressure. The design is checked against what could occur under all possible operational conditions, for example:

- The hydraulic pressure gradients under steady flow conditions at the different flow rates;
- Static pressure under no flow conditions; and
- Pressures developed under transient flow conditions, particular account being taken of surge * effects.

From these operating modes it is possible to define the best location for the pump stations, their power requirements, the sub-division of the pipeline into several sections and the positioning of the valves. The operating pressure can be defined as the pressure required to maintain a given flow rate through the pipeline taking into account the pipeline profile and the residual pressure at the end of the pipeline. The design pressure must be equal to or higher than the maximum operating pressure under any flow condition, including static pressure under no flow conditions (pumps running against closed valves).

The minimum wall thickness is calculated (including a safety factor) from a knowledge of the pressures, type of steel pipe and consideration of other factors. These include the ease of handling without damaging pipes, the resistance to stresses imposed during pipeline construction, and the resistance to deformation under external loads.

The thermal stresses are also considered, together with hydraulic, mechanical and fatigue stresses, in order to ensure that the maximum allowable stress values are not exceeded for the selected wall thickness for the pipeline.

Provision is made where necessary for suitable devices to automatically limit the maximum pressure excursions due to surge caused by transient flow conditions.

In recent years the use of intelligence pigs (**See Section 5.4.3**) for inspecting the condition of pipelines has increased. When it is intended to use pigs, particularly intelligence pigs, special considerations have to be made in the mechanical design. Launching traps and receiving traps * must be suitable for their operation and all bends must have adequate radii. (**Section 5.4.2.2** reviews internal inspection).

All pipes and ancillary equipment which may be incorporated into a pipeline are rated to withstand design pressures and loads, which are at least those used for the pipeline.

5.1.4. Mechanical Protection

Isolation valves are installed along the pipeline route so that the pipeline can be quickly divided into sections in the event of an emergency to minimise the available contents that could spill. Various Codes of Practice make recommendations on the spacing of valves, particularly in areas of dense population.

In certain circumstances non-return valves are installed in the place of isolation valves. These valves only permit flow in one direction and prevent the contents of the pipeline draining back to a rupture point in an emergency, thereby reducing any spillage.

Overpressure protection devices, such as pressure relief valves may be installed at appropriate locations to limit the maximum pressure of the pipeline under transient or incorrect operating conditions.

A compromise is required on the number of valves and fittings in the main line as the more that are introduced the greater the possibility for valve seal or flange leakage.

5.1.5. Corrosion Protection

In the previous report [1], corrosion was cited as the most frequent cause of pipeline failure, although the quantities of spillage from corrosion failures were usually very small. This is no longer true as Third party Damage is more frequent. However, corrosion is still an important cause of failure. It can occur either on external or internal surfaces and different prevention methods are used in each case. CONCAWE incident data [3] show that of the two causes, external corrosion contributes to more spillage incidents than internal corrosion.

5.1.5.1. External Corrosion

Corrosion is electro-chemical in form. When an unprotected pipe is buried in moist soil conditions, an electric current flows from the metal (the anode) to the soil (acting as cathode). The metal from which the current flows will dissolve in the surrounding moisture. This is apparent as corrosion. There are two ways of preventing this corrosion, either by isolating the pipeline from the soil with an electrically insulating protective coating, or by cathodic protection which ensures that any current flow will be from the soil to the metal and not vice versa.

Though it is possible to use the two methods independently, they are commonly used to complement one another. If for example the coating has a fault, then the cathodic protection will protect the line.

Pipeline coatings are applied to the pipeline either during manufacture of the steel pipe or during construction. In the former case, additional protection is applied to the joints during construction. The manufacturing methods, material properties, application techniques and testing procedures for protective coatings are governed by national and international standards. However, these coatings can be damaged during construction or operation or may deteriorate with time and it is therefore normal to both coat the pipeline and to provide a cathodic protection system.

Cathodic protection is an efficient and well proven technique and is specifically tailored for each individual application.

Special consideration must be given to sections of the pipeline where other forms of electrical interference such as power cables or overhead transmission power lines are present. Sometimes it is necessary to install insulation joints at intermediate locations along the pipeline thereby dividing it into electrically independent sections.

5.1.5.2. Internal Corrosion

Internal corrosion has not proved to be a major cause of failure to pipelines transporting crude oils or most oil products. However, in the few circumstances where corrosive products are to be transported there are methods to limit corrosion such as inhibitors and internal coatings. Pigs are frequently used to displace any corrosive products including water that may settle and collect at the low points of the pipeline. The ability to monitor corrosion conditions is discussed in **Sections 5.4.2 & 5.4.3.**

Inhibitors work by forming a protective film on the internal surface of the pipeline, thereby reducing corrosive interaction with the product. The inhibitor has to be specifically selected to avoid contaminating the product being transported and would normally be continuously injected.

Internal coatings are of benefit in certain circumstances. Their application and long term integrity need thorough assessment.

5.1.6. Natural Hazard and Third Party Protection

In areas where significant natural hazards occur and it is not possible to re-route the pipeline, special precautions are taken in the design. These can involve increasing the strength of the pipeline, stabilising the surrounding ground and installing instrumentation to record earth movements such as subsidence which are likely to produce excessive stresses in the pipeline.

Landslides and subsidence such as in mining areas can be detected and the stresses on the pipeline produced by these phenomena can be monitored, for example, by topographical surveys, and/or strain gauges as well as monitoring instruments installed at locations of high risk along the pipeline. Where ground movements are detected, rectification measures can be implemented where necessary.

In areas where there is a high risk of third party damage, such as near highway boundaries, pipelines can be safeguarded by additional protective measures.

To ensure that the integrity of the pipeline is maintained, it is common practice to regularly patrol the pipeline wayleave (see **Section 5.5**).

Pipeline facilities such as pump stations and tank farms are generally protected by enclosing them in security compounds with access only permitted to authorised personnel.

5.2. CONSTRUCTION

Safety is a major factor during the design of a pipeline and continues to be an important consideration during the construction and commissioning phases. Construction requires the successful co-ordination of technical, financial and human resources in order to complete the pipeline to the specified quality, on programme and at the required cost.

Detailed engineering studies for the construction of the pipeline are completed. Technical specifications are prepared which are used as the basis for tenders for equipment, their purchase, inspection and installation.

Each equipment and construction order contains a technical specification which typically includes a detailed description of the needs of the client, from standards through to testing. Emphasis is being placed on quality assurance and control.

Firms selected to receive orders for equipment or contracts for services will have been selected after a stringent pre-qualification procedure.

The inspection of the equipment and the works is either performed directly by the client or by a specialised inspection organisation appointed by the client. It takes place at all critical steps of construction from suppliers' factories through to final inspection of works on site. In this way the owner/operator can ensure that these items comply with the order requirements.

When construction is complete, precommissioning operations are carried out. This work includes pipe cleaning, leak and pressure testing and gauging * for pipe deformation. It may be useful to carry out an initial on-line inspection (see **Section 5.4.3**) to establish a baseline of the condition of the pipeline.

An important safeguard is introduced at the end of construction with the hydrostatic pressure test of the installed pipeline. Water is used to pressurise the pipeline up to a point well beyond the normal operating pressure and then held at this level for normally 24 hours. This test establishes the strength of the pipeline and its components, and proves its leak tightness. The pipeline system integrity is thereby established.

5.3. COMMISSIONING

Upon completion of the precommissioning the pipeline is handed over for commissioning. It is during commissioning that the owner/operator carries out operational tests and makes any necessary adjustments prior to operating the pipeline.

Complete documentation is kept at every stage of the pipeline construction and upon completion a reference book is typically prepared for the pipeline.

5.4. OPERATION

An operating pipeline requires control, maintenance and surveillance. The control centre monitors the variables through the instrumentation on the pipeline in order to ensure safe and efficient operation. Maintenance is conducted on a planned formal basis. Surveillance is carried out regularly to check the general condition of the pipeline route and to ensure that no unauthorised work is being started near the pipeline and to check that the pipeline is not endangered in any other way. Such surveillance can be carried out either from the air or on the ground or both.

5.4.1. Control Room

The control room is the nerve centre of a pipeline. The essential instrumentation on the pipeline is linked to the control room by cable and/or telemetry. The increasing power of computer systems available to pipeline operators enables ever more sophisticated pipeline supervision and control. Current technology enables pigs and product parcels to be tracked; leak detection on pumping pipelines by mass/volume balance or dynamic modelling is becoming increasingly reliable and accurate. Monitoring of pressure (and temperature) also ensures a leak detection capability for a pipeline that is shut in.

The instrumentation monitors variables such as pressures, flow and temperatures in the pipeline and external conditions such as ground movement and air temperature.

The control centre staff are trained and qualified personnel who are able to use this information to control and operate the pipeline within the design constraints.

Automatic alarms on the pipeline are also linked to the control room to alert the staff in the event of an emergency. The control room staff are trained in emergency procedures and have available an emergency service call out list, full technical details of the system and spillage control systems. Records are kept of the full operating history of the pipeline and of all maintenance carried out.

No work is permitted on a pipeline or in its vicinity without a Permit to Work issued by the control room and approved by an authorised engineer.

5.4.2. Inspection and Maintenance

Routine inspection and maintenance is carried out to ensure that the pipeline is in mechanically sound condition and operating at optimum efficiency. Regular surveys are undertaken to check for corrosion and remedial work is carried out if necessary. All instruments and cathodic protection systems are checked for correct operation. Deposits are removed from the internal pipe wall with scraper pigs to reduce pressure losses in the pipeline.

5.4.2.1. External Inspection/Maintenance

Indications of the need for external maintenance could come from a number of sources; for example, a survey to monitor any changes in the voltage levels at the cathodic test points and/or inspection pig data.

Cathodic protection surveys are performed to check that this system is functioning correctly, as it is possible to detect from the survey results whether there is an indication of deterioration in the external coating or outside interference on the electrical system.

When there are indications that there could be corrosion on the exterior of a pipeline it is necessary to excavate the pipeline at that point and complete a local assessment of the corrosion. Repairs to the outside of the pipe can then be carried out if necessary. Since the excavation and inspection of the pipe is an expensive operation, experience in assessing the early indications of external corrosion has developed over the years.

5.4.2.2. Internal Inspection/Maintenance

There are several methods for checking the internal pipe-wall condition of a pipeline and these include corrosion coupons, intelligence pigs and iron counts.

The highest uncertainty for the fitness for purpose analysis is often in the assessment of the degradation rate, particularly in the case of corrosion. Although corrosion is often localised and dependent on on-site conditions, and corrosion rates are not linear in time, various methods have been developed to assess the corrosion induced rate of pipeline deterioration.

Some operators have developed corrosion models to predict CO_2 corrosion rates. Though these models have been refined to take for instance velocity effects and scaling into account, they still provide a conservative prediction.

Various monitoring and inspection tools are used to assess the actual corrosion growth rate. Internal corrosion growth can be assessed using corrosion coupons or probes, and/or external measurement devices like mechanised ultrasonics and field signature monitoring. A corrosion coupon is a strip of metal inserted into a pipeline which is then periodically monitored for corrosion either by electrical methods or by periodical removal and weighing. This can be performed with the pipeline in service. Unfortunately, the corrosion growth is underestimated when these measurement devices are not located at the worst corrosion spots.

A common method to detect internal corrosion is the monitoring of the quantity of dissolved iron in the small quantities of entrained water. The accuracy of the method is dependent on the water pH and the level of iron in the liquid. This method is particularly useful in indicating the level of effectiveness of the inhibitors commonly added in oil pipelines. It is not used in isolation, but in combination with other methods of corrosion monitoring, as each method complements the other and provides supporting data on the condition of the pipeline.

Another option to assess corrosion growth is by comparison of two intelligence pig surveys. Conventional cleaning pigs are used to scrape away any deposits that have accumulated on the interior wall of the pipeline to reduce pressure loss.

5.4.3. Intelligence Pigs

Intelligence pigs are being used on a regular basis to assess the condition of pipelines. Intelligence pigs provide information on the extent and severity of defects over the entire length of the pipeline, which is a major advantage compared to other techniques.

Such pigs can be passed through a pipeline during normal service and with specialised instrumentation they record information on the condition of the pipeline. The pipeline has to be designed to enable accommodation of the type of pig envisaged. Constraints on their use, typically found in older pipelines, are for example tight bend radii, variable pipeline diameters and open branches off the main pipelines. Various types of these pigs can be used to locate and quantify pipeline geometry defects, such as dents or buckles, and locate and quantify wall thickness metal loss caused by internal or external corrosion, erosion or mechanical damage.

The most frequently used intelligence pigs aim to detect metal loss, e.g. due to corrosion. The measurement principle of these tools is either based on ultrasonics or on magnetic flux leakage (MFL). A more recent development is a high frequency eddy current pig to detect low level internal corrosion in small diameter, heavy wall pipelines. Other regularly applied intelligence pigs aim to detect mechanical damage as for instance dents, wrinkles, buckles and ovality.

Metal loss due to corrosion can be detected by intelligence pigs although with varying degrees of reliability and accuracy. A number of specialist service companies continue to develop the capabilities of their intelligence pigs. Increasing sophistication enables the more accurate sizing and location of corrosion defects.

The need for intelligence pigs that can detect cracks was identified a number of years ago and several projects have been carried out to develop such pigs. Pigs capable of detecting cracks are now available but not as yet for all sizes of pipelines.

The inspection capabilities of intelligence pigs are continuously improved by developments of sensor technology and on data processing, storage and analysis. Capabilities/limitations for Magnetic and Ultrasonic tools are shown in **Table 3**.

Table 3 Intelligence Pigs - Differences Between Magnetic and Ultrasonic Tools

Magnetic Tools	Ultrasonic Tools
Available Diameters ≥ 4”	Available Diameters ≥ 6”
Indirect Measurement	Direct Measurement
All fluids possible	Only homogeneous liquid (slug)
Smooth metal loss difficult	Narrow pits difficult
Verification / calibration often required	No verification (except external defects vs laminations)
Sizing capability ± 20% wall thickness	Sizing ± 1mm
Maximum wall thickness limit	Minimum wall thickness limit
Moderate cleaning required	Thorough cleaning required
Tool speed range 0.5 to 4 m/s.	Maximum tool speed 1 –2 m/s

Despite all improvements on the mechanical design of pigs and on the inspection technology, intelligence pigs should not be used as a black box. Defect assessment tools and guidelines are required for the various types of defects in order to determine the acceptability or otherwise of defects. Each different technique and tool have inherent limitations on inspection capabilities that should be realised and selection should therefore be based on the inspection requirements.

5.5. SURVEILLANCE

Surveillance of a pipeline is achieved by regular patrols. Depending on the terrain, vegetation, length of line to be covered and local legislation, these patrols may be made from the air or on the ground. They check the condition of the easement * and the pipeline markers and identify any activity in the vicinity of the pipeline. Aerial patrols have historically relied on visual observation and written reports; recent developments of video technology are permitting permanent records of the condition of the pipeline route to be made for retention and analysis.

On sections of pipelines prone to ground movement, suitable monitoring of the ground and the pipe is carried out.

5.6. CONTROL OF THIRD PARTY INTERFERENCE

In most countries, authority requirements stipulate notification of major excavations and building works within a specified distance of the pipeline prior to their commencement. This gives the pipeline operator the opportunity to object to developments that may affect his pipeline. If work must be undertaken near a pipeline, the pipeline operator will advise of the precautions necessary to ensure the integrity of the pipeline system. In most instances it is essential that such work be witnessed by a supervisor employed by the pipeline operator.

A wide range of techniques are used by various pipeline operators to diminish the risk of damage to pipelines by third parties. A summary of the procedures used in the various countries is given in **Table 4**.

Table 4 Methods to Control Third Party Interference

COUNTRY	EXISTENCE OF ONE-CALL SYSTEM	PIPELINE OPERATOR ACTIONS	PIPELINE OPERATOR LEGAL LIABILITY
Austria	No central information system in place.	Communications to authorities and landowners remind them of the existence of the pipeline.	Specific legislation exists whereby the third party excavator must inform the pipeline operator prior to commencing work. Agreed procedures must be in place prior to commencement.
Belgium	Central information system ('100' system) in place for reporting of emergencies, caller is connected to nearest local emergency centre. Pipeline operators keep emergency centres up-dated on pipeline details. Excavators must verify details of underground services at local Town Hall & inform pipeline operators prior to commencing work. This is a legal requirement.	Pipeline operators keep local Town Halls updated on all pipeline route details. Also keep the police, fire, ambulance & '100' system updated.	Pipeline operator is held legally responsible for the consequences of any third party incident. Operator would need to prove he had taken all reasonable precautions in order to avoid being held accountable for all financial consequences of third party damage.
Denmark	No centralised information system in existence yet.	Land owners & Authorities kept updated & reminded of pipeline route.	No specific legislation but under Danish Law the third party would be held accountable for damage costs.
France	An attempt was made to establish a central service at national level but this was unsuccessful	Co-ordinated publicity efforts carried out to keep public & industry informed of pipeline existence; i.e. posters brochures / safety signs, etc.	Specific legislation exists which requires declarations to be made for carrying out works in the vicinity of pipelines.
Germany	No central information system in existence.	Communications to authorities and landowners remind them of the existence of the pipeline.	Specific legislation exists whereby the third party excavator must inform the pipeline operator prior to commencing work. Agreed procedures must be in place prior to commencement.
Italy	No central information system in place.	Annual communications to Authorities to remind them of the existence of the pipe-lines.	No specific legislation in place. In the event of third party damage, each party would need to prove it had taken all reasonable precautions.

***Table 4** (con)* Methods to Control Third Party Interference

COUNTRY	EXISTENCE OF ONE-CALL SYSTEM	PIPELINE OPERATOR ACTIONS	PIPELINE OPERATOR LEGAL LIABILITY
The Netherlands	A comprehensive one-call service is provided by the Cables & Pipeline Information Centre (KLIC). Excavators call KLIC who advise the pipeline / cable owners who then provide detail to the excavator. Three days notice is required.	Pipeline operators carry out regular surveillance from the air, by road & on foot. Many oil pipelines are in well defined multi-user pipeline corridors.	The existence of the KLIC places the onus on third party for any damage incidents, providing correct information has been supplied.
Norway	No centralised system in existence.	Local authorities, police, fire brigade & emergency co-ordinators kept informed of pipeline route details.	No information available.
Spain	No central information system in existence.	Local Authorities and Police kept informed of pipeline route details.	No specific legislation available. If third party damage occurs, each party would need to prove that it had taken all reasonable precautions.
United Kingdom	No centralised information systems in England & Wales. There is a centralised system in Scotland called SUSIEPHONE.	Utilities companies & industry kept up-to-date on pipeline route details by Linewatch public information programmes run by product pipeline operators. Local Authorities & Emergency Planning Centres kept updated on pipeline routes & Emergency Plans.	No specific legislation in place, cases would proceed via common law & judged on the merits of the case & whether reasonable precautions had been taken by the parties involved. Pipeline operators could be liable to prosecution under the Environment Act and the Pipeline Safety Regulations in cases of oil spillages / pollution.

In all countries, pipeline routes are marked (frequently with a contact phone number), emergency plans are prepared and regular surveillance is undertaken.

In a number of instances, this table refers to “One-Call systems”. The idea of these is that a person intending to carry out ground works only has to phone one number for a check on whether these works may impinge on a pipelines or other underground services. They are exemplified by the KLIC system in the Netherlands. In this system, the cable and pipeline operators have established a database in which these utilities are delineated. The database is not open to public search, but anyone intending to carry out excavations is supposed to contact KLIC giving details of their proposed activities. KLIC then checks whether these are liable to interfere with a cable or pipeline, and if so, notifies the operator who then contacts the excavator.

5.7. EMERGENCY RESPONSE

The main priority in dealing with a pipeline failure is to safeguard people and property and limit the impact of the product release to the environment. The effects of major incidents and accidents can be substantially reduced if relevant and well-tested emergency response systems are available.

Emergency response systems typically consist of:-

- Plans and procedures
- Trained personnel
- Equipment and materials

It is important to realise that the total amount of commodity finally lost depends not only on the capability of early detection but also on rapid response. Emergency plans are available which establish all possible types of emergency situations and which then provide a set of guidelines that can be used to deal with them effectively, should they occur.

6. LEAK DETECTION

6.1. INTRODUCTION

Although spillages are in fact very rare, leak detection systems are installed to detect and locate a leak as soon and as accurately as possible. These systems allow the operator to take the appropriate action to control and reduce the spillage. Detection techniques are based on either continuous or intermittent measurements of specific parameters. Intermittent leak detection methods are often able to detect smaller spillage rates compared to continuous leak detection techniques.

Some continuous techniques can only detect transient pipeline conditions during the onset of a leak, and will not be able to identify the presence of a leak at a later moment in time.

For some intermittent techniques, fluid transportation through the pipeline needs to be interrupted. Using such intermittent techniques, the detection time of a leak will be completely dependent on the frequency of inspection.

The conflicting balance of sensitivity to leaks and false alarms will determine the sensitivity of the leak detection system. Large leaks can normally be detected more rapidly than small ones. However, attention also needs to be paid to avoiding false alarms as well as attempting to shorten the leak detection time or to reduce the minimum detectable leak rate of a leak detecting system in order to retain the user's credibility of the system.

The performance of pipeline leak detection techniques is dependant on fluid type, operating pressure (including fluctuations), mode of operation (batch or continuous), pipeline length and size, metering accuracy, etc.

The decision as to which technique to adopt depends on a detailed case by case evaluation. When the consequences of a spillage are considered significant then the more sophisticated techniques of leak detection are required. It may be necessary to deploy more than one leak detection technique in order to achieve the desired leak detection performance.

6.2. PRINCIPLES AND METHODS

Although there are numerous leak detection methods available, the detection principles are limited and can be summarised as follows:

- Visual observation and other off line leak detection methods
- Comparison of input volume with output volume
- Analysis of pressure and/or flow rate measurement
- Monitoring of characteristic signals generated by a leak
- Leak detection pigs *

A summary of the capabilities and application areas of the various leak detection techniques is given in **Table 5**.

Table 5 Capabilities and Application Areas of the Various Leak Detection Techniques

LEAK DETECTION METHOD	LEAK DETECTION CAPABILITY	MODE OF OPERATION	RESPONSE TIME	LEAK LOCATION CAPABILITY	REMARKS
Low pressure	Major leaks	Any	Seconds to minutes	Between block valves if pressure readings available	Commonly used, high thresholds to avoid false alarms
Pressure decrease / flow increase	Large leaks	Steady state	Seconds to minutes	Between block valves if pressure readings available	
Pressure gradient along the pipeline	Large leaks	Steady state	Minutes	Between block valves if pressure readings available	Onshore only
Negative pressure wave	Medium leaks	Steady state	Seconds to minutes	Within 1 km	Detects only the onset of a leak
Wave alert	Small to medium leaks	Steady and transient state	Seconds to minutes	Within 1 km depending on transducer spacing	Detects only the onset of a leak
Volume balance	Medium to large leaks	Steady state	Minutes to hours	None	
Corrected volume balance	Small to medium leaks	Steady and transient state	Minutes to hours	None	
Dynamic simulation	Small leaks	Steady and transient state	Minutes to hours	At best, within 10% of pipeline length	
Statistical leak detection	Small leaks	Steady and transient state	Minutes to hours	Indication only	Low probability of false alarm
Ultrasonic leak detection pig	Small leaks (typical 50 l/h)	Intermittent	Depends on pigging frequency	Within 100 m	
Acoustic reflectometry	Large leaks (on-line), small to medium leaks (shut-down)	Steady state	Depends on monitoring frequency	Within 1 km	
Differential static pressure test	Small leaks (hard liquids) medium leaks (soft liquids))	During shut-down	Hours to days	None, between block valves	Capabilities depend on length & temperature effects
Sniffer tube, hydrocarbon sensing cables	All fluids, including multiphase: small leaks	Any	Hours	Within 100 m	Short lines only

6.2.1. Visual Observation

Where spillages have occurred they have often been detected through visual observation, either by company operators or by people passing by.

The source of spillage is not always easy to locate because of the migration of oil through the ground. The distance between the location of the leak and the site where the traces of oil are discovered may vary depending on soil conditions and nature of the terrain.

Visual observations can often generate false alarms because the spillage may be due to sources other than the pipeline, such as unauthorised disposal of products similar to that in the pipeline.

6.2.2. Comparison of Volume Input with Volume Output

If the condition of the product in a pipeline were perfectly constant, the volume pumped into the line would exactly equal the volume flowing out. Any difference between the two volumes would signify a leak.

The condition of a product entering a pipeline is, however, subject to variation in volume due to changes in temperature, pressure and density as the product is transported in the pipeline. The size of spillage which can be detected is dependent upon the accuracy with which these changes can be measured.

The volumes of product flowing into and out of the pipeline are measured by flow meters at each end of the pipeline which are compensated for temperature and pressure fluctuations.

Variations of the product within the pipeline can either be estimated at pre-set comparison times from measurements of the variables, at regular intervals along the pipeline, or predicted by computer model. The difference between the quantities flowing into and out of the pipeline are corrected to take account of the variations within the pipeline. If the difference exceeds a preset limit an automatic alarm is given. The more often a comparison is made, the faster a leak will be detected. However, this technique does not locate the leak nor does it necessarily recognise small, slow leaks.

If there are large changes in elevation in the pipeline profile, a condition called 'slack line' * can develop. In these sections the pipeline may not be full of liquid, which may cause difficulties in applying volume comparison.

6.2.3. Analysis of Pressure and/or Flow Rate Measurements

The flow of a product through a pipeline produces a pressure drop along the pipeline that is directly related to the flow velocity. Deviation from the expected flow velocities and pressure drops in normal operation can therefore indicate a leak.

The operator monitors the pipeline for such variations and an automatic alarm is raised if the change exceeds a set limit. Small variations in measured conditions can also be caused by sources other than leak and consequently the accuracy is related to the size of the leak. It is becoming possible to generate a computer model of the pipeline behaviour, and if the measurements received deviate significantly from the computer model, an alarm is raised. This technique does not generally locate the leak. Recent experience of such modelling techniques is that these systems may not reliably detect leaks for more complex multi-ingress, multi-egress pipeline systems transporting multiple products.

Static pressure tests can be performed while the pipeline is shut down in order to confirm its integrity.

6.2.4. Monitoring of Characteristic Signals Generated by a Leak

A rapidly occurring leak in a pipeline generates a transient negative pressure wave which travels away from the leak location in both directions at the velocity of sound (approximately 1,000 m/s in crude oil).

Detectors located at regular intervals along the pipeline will detect immediately the negative pressure wave and will give an estimate of the location of the leak. However, pressure transients generated by upstream and downstream facilities can cause false alarms so that a sophisticated system is required to eliminate spurious signals. Small and slowly developing leaks cannot be detected by this method.

6.2.5. Leak Detection Pigs

Liquid escaping under pressure through a defect in the pipeline wall generates ultrasonic noise. This noise can be measured and recorded by a pig propelled through the pipeline by the normal flow of the product. Even small leaks can be detected and located with a good level of accuracy.

This method will not alert the operator immediately the leak occurs nor will it indicate the size of it. The technique is used instead for locating and assessing suspected leaks, or conversely, to confirm the integrity of the line.

6.3. DEVELOPMENTS

Continuous efforts are being made by the industry to improve the performance of leak detection systems. Systems are being proposed, such as acoustic transducers or a 'sensor cable', but these are presently not practical for cross-country pipelines

Improvements in instrumentation, and better software programs will improve the sensitivity of leak detection equipment and reduce the number of false alarms.

7. CONTROL OF SPILLAGES

The prevention of spillage is a primary concern for every pipeline operator. However, when it does occur, rapid detection and location of the spill, coupled with well planned control procedures will minimise the volume spilled. Measures taken include the following:

- Reduce the pressure and the leakage rate by shutting down or starting pumps and by closing or opening valves according to the emergency procedure.
- Notify the emergency services and inform the authorities.
- Recover as much of the spillage as is possible.
- Clean up the spillage area and ensure all precautions have been taken to minimise damage to the environment.
- Repair and recommission the pipeline.

Efficient execution of the above actions will reduce the net loss of product and hence the environmental impact, and minimise the time that the pipeline is out of operation. Such efficient execution can only be achieved if the pipeline operator has well equipped and well trained emergency response teams available to him. Regular emergency exercises, both to train personnel and eliminate shortcomings in procedures and equipment are invaluable.

8. EMERGENCY PROCEDURES AND REPAIR METHODS

Emergencies can occasionally occur and to be in a position to deal with them, advance precautions are taken by pipeline operators. Manuals on emergency procedures and repair methods are developed for each pipeline system and are generally based on the national statutory requirements and internal company standards and procedures. Repair equipment and materials are normally available for each pipeline system so that repairs can be made rapidly in the event of an emergency. Sometimes these are shared between companies operating the same pipeline sizes.

8.1. EMERGENCY PROCEDURES MANUAL

The purpose of the manual is:

- To assist operating personnel to take necessary actions to lessen the effects of any incidents and to advise on the location of rescue and pollution control services.
- To provide a list of the public and local authorities who should be advised in the event of an incident.
- The manual includes details of the following: -
  - ⇒ The necessary actions to control the pipeline. These will include reducing or stopping the flow.
  - ⇒ The lines of communication to and from the authorities.
  - ⇒ Location and use of emergency equipment.
  - ⇒ Public emergency services, e.g. rescue, medical assistance, pollution control.
  - ⇒ Operators or other services in the vicinity of the pipeline that might be affected by the emergency.
  - ⇒ Pre-start checks prior to re-using the line after an emergency.
- The manual is issued prior to the commissioning of the pipeline and updated as necessary.

8.2. REPAIR METHODS MANUAL

The intention again is to develop contingency responses to various pre-conceived situations. The manual includes, amongst others, details of the following:

8.2.1. Inspection procedures necessary to ascertain the type of damage.

In the event that a pipeline is damaged, or there is a suspicion of damage, the pipeline must be inspected to ascertain the extent and nature of the damage. Prior to any work being carried out, all necessary precautions must be taken to make the pipeline and surrounding areas safe and ensure safe working conditions for those involved in the inspection and repair. This will often involve reducing the pipeline pressure.

Access to the damaged section will generally require excavation and removal of the external coating. Following an initial visual inspection, the most appropriate form of non-destructive testing is carried out to identify and assess the severity of the damage.

In order to investigate more fully the cause of the damage, additional measurements and actions e.g. ground resistivity, pipeline potential, additional non-destructive testing, collection of soil samples, etc. may be required.

8.2.2. Defect assessment

The defect assessment takes into account the type, size, and position of the defect, wall thickness, steel quality, pipeline configuration in the vicinity of the defect, operating conditions, pipe stress situation, pipeline history, etc. The classification of the damage types is made according to in-house experience and research projects. This determines what damage is acceptable based on the operating and design conditions of the pipeline.

Within the pipeline industry, one of the most commonly used methods for the assessment of metal loss defects is the ASME B31 G [5] method. This method is a semi-empirical approach developed by the Batelle Institute. The method gives the relation between the acceptable length and depth of a metal loss defect and the required derating in case a defect is not acceptable. Research on burst resistance of pipelines by a number of companies and institutes is ongoing and has resulted in proposals for modified assessment methods and/or guidelines.

8.2.3. Repair Methods and Procedures

Once the defect classification is completed, it is decided which of the various repair methods is appropriate depending on national and company regulations, operational requirements and safe access to the pipe with the repair equipment.

A variety of repair methods are available but a consideration of these is outside the remit of this report.

Additional actions to ensure safe repair work may include a further reduction in pressure, consideration of geological conditions, soil stability and necessity for foundations, inspection of adjacent girth welds and evaluation of possible changes in the pipe stress situation during and after repair.

8.2.4. General Quality Management

The preparation, inspection and repair work should be performed taking into account some quality requirements as follows:

- in accordance with relevant safety and environmental regulations
- prior notification of relevant local authorities
- notification of other operators with plant in the vicinity of the pipeline.
- compliance with approved procedures for inspection, defect assessment, repairing and welding
- use of qualified personnel for testing, welding on live pipelines and specialised repair methods.
- documentation of defect history and pipeline repair.

9. GLOSSARY

Abandonment	The procedure used when a pipeline has come to the end of its economic life. The pipe may or not be removed, but in either case is cleaned of all oil residues and made safe.
Cathodic Protection	A system to eliminate corrosion at places of exposed bare metal pipe surface by forcing an electric current to flow through the conductive soil towards that surface.
Coating	A protective layer attached to the pipeline to isolate the pipe from the surrounding ground in order to prevent corrosion.
Easement	A legal agreement to allow access for the purpose of construction and maintenance of a pipeline.
Gauging	Checking to ensure that the ovality of the pipeline is within specification by the use of a special gauging pig.
Hazard	The intrinsic property of a substance, condition or object to cause harm without any assessment of the likelihood of harm occurring.
Inspection pig	A pig used for inspection of the pipeline. This includes geometry, internal and external corrosion and product release. A special type of instrumented pig is commonly referred to as an intelligence pig.
Intelligence pig	See inspection pig.
Pig	A device inserted into the pipeline and carried along by the flow of the material being transported for various reasons, particularly cleaning or inspection.
Traps	Devices placed at the beginning and end of a pipeline for **Launching** or **Receiving** pigs without interfering with the flow of material in the pipeline.
Spillage	The accidental loss of oil from the pipeline system. The **Net** volume spilled is the volume lost after recovering oil from the **Gross** volume of liquid spilled. The minimum volume considered for the purposes of the CONCAWE statistics is 1 m3.
Risk	The product of the hazard (see above) multiplied by the probability of its occurrence.
Slack Line Conditions	A slack line occurs in pipeline sections (mountainous areas) where the pipeline is not full of liquid due to local hydraulic conditions.
Surge Pressure	A pressure wave travelling along a liquid pipeline at the speed of sound in the fluid. It is caused by liquid flow suddenly being restricted or brought to rest due to, for example, a pump tripping or valve suddenly closing.

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The largest source of oil pollution in coastal waters is not the numerous disasters happening along the European coasts which only represent 5 % of the total amount of oil spilled in water (6.11 million tonnes in 1973, 2.35 million tonnes in 1990), but the continuous pipelines leaks and runoff, with 61 % of oil coming from river oil pollution and. urban runoff and 30 % due to intentional discharges from tankers.Â Its 145th article require member states to cooperate in the field of prevention, reduction and control of pollution to the marine environment, including the coastline. Particular attention must be paid to the need for protection from harmful effects of such activities as drilling, dredging, excavation, disposal of waste, construction and operation or maintenance of pipelines. The European oil and petroleum product pipeline incident data originating from CONCAWE incident reports and its analysis are covered in Chapter 2. The U.S. oil and hazardous liquid pipeline incident data obtained from the PHMSA incident reports and the detailed analysis is discussed in Chapter 3. The report concludes with the overall findings of the study and recommendations given in Chapter 4. 1. 2. CONCAWE Oil Pipeline Natech Incidents.Â For this purpose, CONCAWE collects spillage data on European cross-country oil pipelines since 1971 with particular regard to spillage volume, clean-up and recovery, environmental consequences and causes of the incidents (CONCAWE, 2013). The CONCAWE inventory covers pipelines that are