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Series on Chemical Accidents No. 2

Report of the OECD Workshop on Pipelines (Prevention of, Preparedness for, and Response to Releases of Hazardous Substances)

ORGANISATION FOR ECONOMIC CO-OPERATION AND DEVELOPMENT

Paris

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Series on Chemical Accidents

No. 2

Report of the OECD Workshop on Pipelines (Prevention of, Preparedness for, and Response to Releases of Hazardous Substances)

Environment Directorate

Organisation for Economic Co-operation and Development

Paris 1997

Other publications related to chemical accident prevention, preparedness and response include:

Guiding Principles for Chemical Accident Prevention, Preparedness and Response: Guidance for Public Authorities, Industry, Labour and Others for the Establishment of Programmes and Policies related to Prevention of, Preparedness for, and Response to Accidents Involving Hazardous Substances (1992)

International Directory of Emergency Response Centres (first edition, 1992) Prepared as a Joint Publication with UNEP-IE [under revision]

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The Organisation for Economic Co-operation and Development (OECD) is an intergovernmental organisation in which representatives of 29 industrialised countries in North America, Europe and the Pacific, as well as the European Commission, meet to co-ordinate and harmonize policies, discuss issues of mutual concern, and work together to respond to international problems. Most of the OECD's work is carried out by more than 200 specialised Committees and subsidiary groups composed of Member country delegates. Observers from several countries with special status at the OECD, and from interested international organisations, attend many of the OECD's Workshops and other meetings. Committees and subsidiary groups are served by the OECD Secretariat, located in Paris, France, which is organised into Directorates and Divisions.

The work of the OECD related to chemical accident prevention, preparedness and response is carried out by the Expert Group on Chemical Accidents, with Secretariat support from the Environmental Health and Safety Division of the Environment Directorate. The objectives of the Chemical Accidents Programme include: the exchange of information and experience; the analysis of specific issues of mutual concern in Member countries; and the development of guidance materials related to chemical accident prevention, preparedness and response. As a contribution to meeting these objectives, about ten other Workshops have been held since 1989.

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The Inter-Organization Programme for the Sound Management of Chemicals (IOMC) was established in 1995 by UNEP, ILO, FAO, WHO, UNIDO and the OECD (the Participating Organizations), following recommendations made by the 1992 UN Conference on Environment and Development to strengthen co-operation and increase international co-ordination in the field of chemical safety. UNITAR joined the IOMC in 1997 to become the seventh Participating Organization. The purpose of the IOMC is to promote co-ordination of the policies and activities pursued by the Participating Organizations, jointly or separately, to achieve the sound management of chemicals in relation to human health and the environment.

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FOREWORD

This report presents the main outputs of the OECD Workshop on Pipelines (Prevention of, Preparedness for, and Response to Releases of Hazardous Substances) which took place in Oslo on 3rd-6th June 1996 and was hosted by the Government of Norway in co-operation with the Governments of France, Switzerland and the United Kingdom and the European Commission. It was attended by 110 experts from 20 countries, representing public authorities at various levels, the pipeline industry (oil, gas and other), petroleum, gas and chemical producers, international organisations, universities and research institutes, and other interested parties.

The aims of the Workshop were to provide an opportunity for experts from different countries and different sectors concerned with pipeline safety to exchange information and experience, to consider issues relating to accident prevention, preparedness and response, and to make recommendations concerning best practice.

The first part of the report contains the Conclusions and Recommendations of the Workshop. The second part is the Discussion Document, an earlier version of which was presented at the Workshop. The Discussion Document was revised by the authors in light of comments received during or immediately following the Workshop.

The OECD's Expert Group on Chemical Accidents recommended that this report be forwarded to the Joint Meeting of the Chemicals Group and Management Committee of the Special Programme on the Control of Chemicals for consideration as an OECD publication. The Joint Meeting recommended that it be made available to the public. It is published on the authority of the Secretary-General of the OECD.

It should be kept in mind that the documents in this publication have not been endorsed by, and do not necessarily reflect the views of, the OECD or its Member countries.

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Workshop Conclusions and Recommendations

Introduction

- 1. The OECD Workshop on Pipelines (Prevention of, Preparedness and Response to Releases of Hazardous Substances), held in Oslo on 3rd-6th June 1996, was hosted by the Government of Norway in co-operation with the Governments of France, Switzerland and the United Kingdom and the European Commission. It was attended by 110 experts from 20 countries, representing public authorities at various levels, the pipeline industry (oil, gas and other), petroleum, gas and chemical producers, international organisations, universities and research institutes, and other interested parties.
- 2. The aims of the Workshop were to provide an opportunity for experts from different countries and different sectors concerned with pipeline safety to exchange information and experience, to consider issues relating to accident prevention, preparedness and response, and to make recommendations concerning best practice. It should be noted that, for the purpose of this text, *safety* encompasses the protection of health, environment, and other assets.
- 3. The participants recognised the timeliness of the Workshop, in the light of the recognition that pipelines will increasingly be used as a form of transport as well as the fact that new government initiatives are being considered or implemented. For example, Switzerland has introduced the risk concept of major hazard prevention into its pipeline legislation for new pipeline projects, the United Kingdom has a new regulatory approach which recently came into force, the United States is considering new legislation in this area, and the European Commission has been requested by the Council of Ministers to consider questions related to pipeline safety in light of the fundamental review of the "Seveso" Directive relating to fixed installations.

General Conclusions

4. The workshop participants agreed that pipelines provide a generally safe and, for certain substances, a vital means for transport. They represent an increasingly important option in light of concerns with other transport modes. Among the advantages of pipelines is the fact that they can move large quantities of hazardous substances quickly, relatively inexpensively, and reliably, with relatively few associated impacts on the environment (e.g. vehicular exhaust, aesthetic impacts, noise, congestion). The disadvantages of pipelines identified at the Workshop include infrastructure costs (which might be funded by the public or private sector) associated with construction requiring long-term planning, the delays inherent in making a pipeline operational, the problems associated with soil protection, and the lack of flexibility in regard to delivery points and quantities which can be transported. The participants recommended that the use of pipelines should be seriously considered when new transportation routes for conveying large quantities of dangerous substances are planned.

- 5. The pipeline safety record indicates that few accidents with significant impacts on health or the environment have occurred in OECD countries. However, there remains the potential for significant loss of containment with adverse consequences. In addition, anecdotal evidence indicates that some non-OECD countries have significantly poorer safety records.
- 6. Therefore, there remains a need to consider means for improving accident prevention, preparedness and response. The industry recognises that its activities should not harm the public or the environment, and that it is in their best interest to maintain a high level of safety. In addition to general business principles aimed at avoiding harm to health or the environment, the industry recognises the value of operating safely in light of the very high direct and indirect costs of any accident, including, for example, injury to the public, damage to the environment, shutdown of business, repair expenses, loss of confidence by customers and the public, as well as the cost of response and clean-up. The industry has therefore generally undertaken to design, construct, operate and maintain pipelines with a high degree of concern for safety. The "Responsible Care" approach with its objective of continuous safety improvements, developed by the (petro) chemical industry, is now being applied to pipelines.
- 7. It was agreed that the pipeline operator has primary responsibility for the safety of its systems. Nevertheless, there was a recognition that an important role remains for governments in providing leadership, and in creating and maintaining administrative frameworks to facilitate the development of the transportation infrastructure, including pipelines.
- 8. National legislation should be clear, enforceable and consistent among different countries (i.e. to facilitate international projects as well as the development and implementation of the internal procedures of multinational enterprises). There should be co-operation and communication between industry and governments in developing and implementing legislation.
- 9. Regulatory approaches differ among countries due, for example, to cultural, historical and geographic factors. They range from more prescriptive to more goal-setting regimes. While there are core elements which are applicable to the regulation of all pipelines, regulatory frameworks need to take account of important differences such as the type of hazardous substances conveyed (e.g. gas, oil, chemical products) and whether networks are on-shore or off-shore. The regulatory framework should take into account the need to protect human health, the environment, property, and other assets.

General Recommendations

- 10. Pipelines are a safe mode of transport in terms of their impact both on the environment and on human health. The use of pipelines, particularly for transporting large quantities of flammable gases and liquids, should be encouraged. It is recommended that governments and industry work together to facilitate the further development of pipeline infrastructure and to consider the advantages for society as a whole of pipeline use.
- 11. Pipelines should be constructed with the most suitable materials available, to ensure their integrity initially and throughout their life cycle.

12. Useful guidance has been developed by OECD, for example the OECD *Guiding Principles*, which provide advice on how to manage hazardous activities and address the role of public authorities, industry and other stakeholders. It is recommended that such guidance be used for pipeline operations.

Data Collection and Sharing

Conclusions

- 13. Workshop participants emphasised the value of learning from the experience of past accidents, incidents, "near misses", and discoveries of problems, as well as from experience with new technology and developments, in order to improve safety practices. In this regard, it was suggested that each company should maintain information on accidents and near misses.
- 14. The participants noted that data on pipeline accidents and near misses are limited in any one country. The fact that major accidents are rare implies the need for pooling information among countries in order to benefit from experience. It was noted that data are difficult to collect, and that data which exist in different countries or collection schemes are difficult to compare. This is due to a lack of standardised criteria for reporting, and to differences in the nature and extent of information provided to the various schemes.
- 15. An analysis of available data shows that a main cause of pipeline accidents is third-party interference (i.e. accidental damage from digging for excavation or agricultural purposes). Other causes include internal and external corrosion, material and construction defects, natural events such as storms, earthquakes, landslides and mining subsidence, and operator errors.
- 16. The difficulty of assessing accidents with environmental consequences was recognised in light of, *inter alia*, the lack of experience with quantifying environmental damage.
- 17. It was agreed that it is important to analyse the causes of accidents which occur, in order to be able to make changes in technology and procedures so as to improve prevention. In this regard, the analysis should take into account not only the immediate cause but also the underlying reason(s) for the accident. For example, when pipelines are designed, foreseen phenomena such as expected mining subsidence are normally taken into account. Consequently, should an accident occur as a direct result of subsidence, the underlying cause could be a design fault.
- 18. Participants discussed the distinctions between different categories of pipelines with respect to the nature of adverse consequences in the event of an accident. For example, gas pipelines create a fire/explosion hazard, whereas the primary concern with respect to oil pipelines is the environmental consequences of spillage, and the primary concern with respect to accidents involving chemical pipelines may be toxic effects.

Recommendations

19. There is a need to improve the pooling and sharing of information concerning pipeline accidents among countries and organisations. Information should also be pooled and shared on the extent of pipeline

Guiding Principles for Chemical Accident Prevention, Preparedness and Response: Guidance for Public Authorities, Industry, Labour and Others for the Establishment of Programmes and Policies related to Prevention of, Preparedness for, and Response to Accidents Involving Hazardous Substances (OECD, 1992).

systems and on the fluids conveyed. In addition, more detailed information should be collected and made available concerning the relationship between failure and the characteristics of the pipeline, in order to better understand the nature and causes of the accident (e.g. relating to the age, size and construction of the pipeline). Industrial organisations and other bodies which collect data should undertake to enhance their databases and to improve co-operation and sharing of information.

- 20. It was recommended that consideration be given to several approaches for improving the ability to share information. The first is the development of comparable criteria for defining accidents and for reporting information to be used in connection with various existing databases. The second is to develop an international database (containing data from both OECD and non-OECD countries) for reporting all significant accidents. In this regard, it is noted that there are industry-developed databases and that the OECD is in the process of implementing a reporting scheme for accidents at fixed installations. It is recommended that industry should lead in the development of harmonized data collection.
- 21. Furthermore, it was recommended that there should be greater collection of information about smaller incidents, which may be "precursors" to major accidents, recognising that these provide important insights into the means for improving prevention.

Means for Assessing the Hazards and Risks of Pipelines

- 22. It was agreed that hazard and risk assessments are useful tools for decision-makers in industry and government with respect to taking actions to improve prevention of accidents and to mitigate adverse effects in the event of an accident. Hazard and risk assessments also assist public authorities in the development of emergency plans and in undertaking land use planning decisions, including routing of pipelines and decisions concerning proposals for housing or other developments near existing pipelines.
- Assessment of hazards and risks takes various forms (differing in their emphasis on qualitative, quantitative, deterministic or probabilistic aspects). Recognising the limited resources available, risk and hazard assessments are useful in informing the decision-making process and provide a means for optimising the allocation of these resources by ranking various available prevention/mitigation measures. Quantified risk assessment is a means for obtaining guidance for decision-making on safety issues by providing the ability to establish a relative ranking of risks. Another method used is the description of accident scenarios taking into account the various preventive measures.
- 24. There appears to be a trend towards more explicit recognition and understanding of risk, in order to improve management and communication among all stakeholders including the public.
- 25. It was suggested that problems exist in the discussion of risk assessments among different countries and organisations due to the lack of common understanding concerning terms and methods. It was noted, however, that there is an ongoing OECD project to provide a computer-based "translator" of different terms and policies related to risk assessment, focusing on fixed installations. This project, if successful, could provide a basis for work in the area of pipelines.
- 26. While improved communication with the public is a generally recognised objective, the participants discussed the difficulties associated with application of risk communication principles in the context of pipelines in light of the number of communities potentially affected by a single pipeline.

Recommendations

- 27. All parties should strive for greater clarity in the assumptions underlying an assessment of hazards and risks, and for transparency in the assessment process, to permit better communication and understanding and to allow for comparisons. Any efforts towards improving consistency and communication concerning risks should take into account the various methods used by different countries and organisations in this area.
- 28. Public authorities and industry in OECD countries should endeavour to share information and experience related to communication with the public concerning pipelines.

Regulatory Approaches

- 29. Although participants recognised that the primary responsibility for the safe operation of pipelines rests with the operator, they acknowledged the roles and responsibilities of public authorities at various levels. The importance of public authorities in setting goals and providing leadership in this area was emphasised. In this regard, it is necessary for public authorities to have sufficient well-trained staff to carry out their responsibilities.
- 30. In addition, the value of a well-developed partnership between public authorities and industry, in order to meet the safety needs of the public and ensure the protection of the environment, was emphasised. In this regard, it was also noted that there may be a need for involvement by other interested parties (e.g. representatives of workers and community-based organisations) in decision-making processes by public authorities.
- 31. Regulatory approaches concerning pipeline safety in OECD countries differ significantly, ranging from more prescriptive to more goal-setting approaches. However, although different approaches may be adopted, industry appears to have similar safety practices in different countries since the importance of maintaining the integrity of pipeline networks is commonly recognised.
- 32. The general survey conducted in connection with this Workshop revealed that there are common elements in most regulatory schemes, including: the definition of a pipeline; a general obligation to operate safely; and some of the issues addressed (design, construction, operation, and maintenance/inspection). Other issues were addressed in only some countries, including, for example, risk communication, emergency preparedness, land use planning, and accident reporting.
- 33. It was noted that there was a trend towards more flexibility in regard to ways of meeting safety objectives, as reflected in movement away from the more "prescriptive" approach towards the goal-setting approach established in the United Kingdom and Norway and that proposed in the United States. This approach allows operators to choose among the most appropriate and cost-effective risk management options to meet their obligations. Although recent actions indicate a trend towards goal-setting and performance-based approaches, it was recognised that in some cases it may be appropriate to use more prescriptive approaches, in light of, for example, cultural and historical factors.
- 34. It was suggested that further efforts are needed to better understand the effectiveness of various regulatory approaches to safety improvement. In this regard, the United States Department of

Transportation was undertaking a voluntary pilot programme to test the relative merits of a goal-setting approach as an alternative to a more prescriptive approach.

- 35. It was noted that there are significant differences with respect to safety practices for onshore and offshore pipelines. For example, in the case of offshore pipelines the focus is on environmental risk and, in that of onshore pipelines, it is on risks to human health and safety. This may lead to the development of different regulatory approaches.
- 36. Given that operators are under a general obligation to operate safely, it was noted that they take additional actions, not required under the applicable regulatory schemes, in accordance with their specific circumstances.

Recommendations

- 37. When regulations are developed or reviewed, public authorities should endeavour to ensure that they are of value and that they are clear, consistent and enforceable. In addition, stakeholders should be consulted during the development/review process.
- 38. Further efforts should be made to share information concerning experience with various regulatory approaches, in order to better understand their effectiveness.

Safety Management and the Use of Standards

- 39. The Workshop focused on the need for the use of safety management by industry, in order to prevent accidents and to prioritise spending on safety. In this regard, it was emphasised that safety management (including pipeline safety management) needs to be considered an integral part of companies' wider overall management systems.
- 40. It was agreed that safety management could be described generally as the systematic application of management policies, procedures, finite resources, and practices to identify, analyse, assess and control hazards and risks in order to protect employees, the general public, the environment and company assets.
- 41. It was recognised that the goals of safety management by industry are achieved by creating high-quality pipelines at the outset to recognised standards, codes and company specifications and by ensuring their continued integrity during operation. The integrity of pipelines is maintained through adequate maintenance, inspection and monitoring (e.g. use of intelligent pigs, patrolling, aerial surveillance) and sound management. An important element in any systematic and formalised approach to safety is the need for auditing and reporting. Continued improvement should be a stated objective which can be achieved by (in addition to regular maintenance, inspection and monitoring) a wider exchange of information among operators, taking into account lessons learned from reported incidents, and utilisation of new technologies and other developments (e.g. in design, construction, planning, operation and maintenance).
- 42. As an example of safety management systems used by operators, PIMS ("Pipeline Integrity Management Systems"), was described by representatives of the pipeline industry. PIMS includes as key elements: clear objectives and policies; a suitable organisation with clear definitions of asset ownership and related responsibilities, and competent and trained staff; adequate standards and procedures; and

performance monitoring and suitable audit/review procedures to identify shortcomings and make corrections. Different companies implement PIMS in different ways consistent with their particular circumstances, including their safety culture.

- 43. PIMS standards and procedures include, *inter alia*: effective education and training (including public education); emergency planning procedures which are regularly tested and reviewed; and accident investigations.
- 44. Another tool for the management of safety of high pressure gas pipelines is the safety index, which is used to rank pipeline sections in order to show where resources are most effectively allocated.
- 45. In the future, improved monitoring of pipelines, particularly in remote locations, might include increased use of satellite communications.
- 46. The industry is currently harmonizing its standards and codes at international level through the ISO, and at European level for gas pipelines through CEN.

Recommendation

47. In light of the positive benefits derived from safety management systems, industry should continue to share its experience and improve the efficiency of individual elements/techniques of safety management systems with the aim of further reducing pipeline accidents.

Additional Mechanisms for Reducing Risk

- 48. Workshop participants discussed a number of different aspects related to reducing the frequency of accidents and/or mitigating the consequences of accidents which might occur.
- 49. With respect to the design, construction and operation of pipelines, a number of measures to reduce risks were identified, including, for example, external impact protection, use of lower design factors, increased wall thickness, increased depth of burial, improved material quality, decreased stress, improved markings, improved route selection, and improved monitoring. As indicated above, limited resources may require that priorities be established to determine the most effective means in given circumstances.
- 50. Participants also discussed the collection of data related to various systems for reducing third-party interference, which was identified as a major cause of accidents. These systems involved different means for ensuring that proper information is circulated among interested parties concerning the location of pipelines in a given area and for facilitating communication between the pipeline operator and the "third party", such as the utility-based or land-based one-call systems. These systems have proven effective where there is significant industry and public authority commitment, and are therefore cost-effective in terms of accident avoidance.
- 51. Surveillance, and dissemination of information regarding the location, of liquid hydrocarbon pipelines was described by a French operator. Measures include bi-weekly monitoring on the ground, bi-monthly aerial surveillance, ground markers at regular intervals along the length of the pipeline, and

dissemination of information to the public using various methods. These measures have led to an incident rate well below the European average.

- 52. With respect to mitigation of accident effects, participants examined land use planning and emergency planning. Land use planning considerations should be taken into account both in the routing of new pipelines, in order to limit proximity to populated areas to the extent possible, and in decisions concerning proposals to build in the vicinity of existing pipelines.
- 53. In the area of emergency planning, the general principles applicable to planning for accidents at fixed installations apply to pipelines. However, it was recognised that difficulties exist in the application of these principles in light of the differences that exist, including, for example, pipelines' length and location and the fact that they are normally unmanned. Further efforts may therefore be needed in order to ensure appropriate response capability in the event of an accident. Moreover, planning needs to be adapted to the specific situation, e.g. based on the hazards associated with the type of substance being transported.
- 54. In general, ageing pipelines do not appear to be a major problem at the moment since most pipelines are still within their design life. However, it was noted that, as pipelines age, additional monitoring may be required in order to continue to ensure their integrity. Consideration will need to be given to reviewing and revalidating pipelines and their operating conditions once they reach the end of their originally intended design life.
- 55. Three options were identified for dealing with pipelines that are no longer in use, i.e. removal, outright abandonment, or abandonment with additional actions. It was noted that care needs to be taken to properly assess all the associated risks of each option on a case-by-case basis, recognising that the best solution in a given situation may be a combination of methods.

Recommendations

- 56. In view of the apparent success of measures which have been introduced to reduce third-party interference (including, for example, one-call systems), consideration should be given by the pipeline industry to a review and, as necessary, the development and implementation of such systems. This should be done in co-operation with public authorities in all regions/countries.
- 57. The pipeline industry should share information concerning pipelines which reach the end of their intended design life.

Workshop Discussion Document: Current Issues and Questions concerning Pipeline Safety

Bethan Morgan and Roger T. Hill²

1. Introduction

This Discussion Document discusses the issues which relate to chemical accident prevention, mitigation and impact from pipelines which carry potentially hazardous materials, i.e. oil and its products, gas, and chemicals. It briefly addresses many of the key issues discussed in the Workshop. It was written to stimulate thought and discussion amongst the participants and has been revised to take into account discussions at the Workshop. The subjects were addressed in detail during the Workshop sessions by individual speakers who are experts in their own field, and therefore the Discussion Document itself should not be seen as comprehensive. Also, whilst an effort has been made to cover the topics as internationally as possible, the authors hope the inevitable gaps in information and potential misunderstanding of emphasis from one country to another will not detract from the value of the document.

The term "safety" as it applies in the context of this Workshop embraces loss of life or injury, environmental safeguarding, and property damage. The emphasis in this Discussion Document, and in the regulators' approach to pipeline standards and practice, is more towards the safeguarding of public health in terms of fatality or injury. However, it should be noted that the same principles of ensuring that loss of containment does not occur, or that there is appropriate response once it has occurred, apply to all these aspects of "safety". The different emphases which the various aspects may impose on the specific approach are highlighted wherever possible.

It is probably a reasonable simplification to state that, in the context of oil and gas pipelines (which represent by far the largest proportion of petrochemical pipelines), onshore high-pressure gas pipelines are of primary concern because of their potential impact on public safety, whereas oil pipelines, both onshore and offshore, are of primary concern because of the environmental risks they present.

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2. The Importance of Pipelines in Transportation

Pipelines provide a vital means of transportation. For example, approximately half the United States' supplies of crude oil and petroleum products, and nearly all its natural gas supplies, are transported by means of pipeline networks. Pipelines are used widely elsewhere and many new pipelines are planned in other parts of the world. In January 1996, *Pipe Line and Gas Industry* reported that 13,900 miles (22,240 km) of new pipelines are planned world-wide in 1996, only marginally less than the 1995 total of 14,000 miles (22,400 km). Most of these new pipelines will transport natural gas, with several major new transmission routes planned. The Europe-Maghreb (Algeria) pipeline is due for completion in 1996, and in Australia the final 230 miles of the Goldfield Gas Pipeline project will be completed this year. Offshore, in Europe, the Interconnector project will connect the UK mainland with Europe, and a new North Sea link to mainland Europe is planned at Dunkerque.

In addition to oil and gas pipelines, many pipelines also supply the petrochemical industry world-wide. Some of these transport toxic substances, such as ethylene, ethane, NGL (Natural Gas Liquids), ammonia (toxic and flammable) and chlorine (toxic).

Pipelines offer a relatively safe mode of transporting hazardous materials, as witnessed by the few recorded incidents of fatality or injury despite the millions of kilometres of pipelines in use worldwide. In fact, per tonne-mile of product shipped, the risk associated with transporting hazardous substances by pipelines is significantly lower than for other forms of transport, such as road or rail, and only marginally higher than for tankers (which is not always a practical solution) (see **Table 1**).

Table 1 Relative safety of modes of transporting hazardous liquids (United States, 1982-85)

Mode	Average annual fatalities	Average annual injuries	Exposure (average annual BTM)	Average annual casualty rate (casualties per BTM)
Rail tank cars	0	49.8	12.3	4.048
Water tankers	0	<1.0	602.1	< 0.002
Highway tankers	5	36.5	26.4	1.572
Pipelines transporting liquids	3	16.5	563.6	0.035

Note:

Casualties = fatalities and injuries

BTM = billion tonne-miles of crude oil and petroleum products

Source: Pipelines and Public Safety

However, when accidents do occur, pipelines have the capacity to cause multiple injuries and fatalities, extensive property damage, and environmental pollution under certain circumstances. Their safety performance has therefore always been an important issue to regulators. Generally, the main

concern with respect to human safety is directed towards onshore pipelines. The main concerns in the case of offshore sub-sea pipelines (away from the platform area) are predominantly reliability of supply and potential environmental impacts. However, there have been incidents involving loss of life in shallow waters when ships have grounded or dropped anchors on gas pipelines causing releases which ignited. The two types of pipelines (onshore/offshore) are usually dealt with separately in legislation/regulations (though not in the new UK pipeline regulations and the Netherlands Standard – see Section 4 below). There is far greater emphasis on the injury and fatality aspects of safety for onshore pipelines than for those offshore (away from the platform or landfall), due to the fact that *public* safety is not significantly involved offshore. This is reflected in the content of this Discussion Document.

3. Pipeline Hazards

3.1 Accidents Can and Do Happen

The materials pipelines carry can be flammable, explosive or toxic, and therefore pipelines do pose a threat to people and property if these substances are accidentally released. Historically, mechanical interference during excavations and other activities close to pipelines has been a major cause of transmission pipeline incidents. Though rare, when such events occur (for example, the methane pipeline rupture in Edison, New Jersey, in 1994), they receive significant media and public attention due to their dramatic nature. Such occasions are good examples of the importance of public perception when addressing risk issues, as the inevitable calls for better regulation and so on are often disproportionate to the risks actually posed (though not always: for example, the call for riser valves following the Piper Alpha disaster – see Section 5.4 below).

In the UK there have been no public fatalities due to failures of the transmission network in some 400,000 km-years of experience. Similar experience has been reported elsewhere in Europe, for example in Germany.

In the US there have been public fatalities (see **Table 2**, next page). Nevertheless, this experience illustrates the relatively low incidence of serious injury or fatality, given the extensive nature of the US pipeline network and the fact that the distribution network causes more fatalities than transmission pipelines, despite the lower pressure, due to:

- the proximity of people to the leak source, i.e. in the home;
- the confined and cluttered space (making explosions possible explosions are highly unlikely in the open air, as they require the gas to be physically confined and the flame front to be accelerated by the presence of obstacles); and
- the presence of ignition sources.

These factors are inevitable if gas is to be distributed into homes. However, the public perception is that similar consequences could result from transmission pipeline leaks, and that they could be many times worse. Whilst some of the circumstances described above do not exist to the same extent for transmission pipelines, the potential for a major incident exists and serious pipeline incidents have happened. Recent examples are the leakage of LPG from a pipeline in the USSR in 1989, which was ignited by passing trains and is estimated to have killed 500+ people, and the rupture of a high-pressure methane pipeline in Venezuela in 1994 which killed 35 people. Therefore, pipeline operators and regulators must address the associated public safety issues. Whilst the safety of offshore pipelines is not

considered to be a major issue *away* from the platform or landfall, there have been a number of incidents in shallow, congested waters such as those that exist in the Gulf of Mexico.

Table 3 lists those incidents reported to the US Minerals Management Service in 1967-90.

Table 2 US incidents and casualties per year with onshore pipelines, 1989-93 (average over five years)

Type of service	Failures	Deaths	Injuries
Gas distribution	131	11	67
Gas transport/gathering	86	5	16
Hazardous liquid	200	2	20

Source: Pipe Line and Gas Industry, February 1996

Table 3 Deaths and injuries associated with pipeline failures (by source, 1967-90)

Accident	Date	Number of fatalities	Number of Injuries	Pipeline type
Placid, Eugene Island	1975	3	0	Gas?
Chevron, Ship Shoal	1979	1	1	Gas condensate?
Sea Chief, Louisiana	1987	2	1	Gas condensate
Northumberland, Texas	1989	11	3	Gas
Sonat/Arco, South Pass block 60	1989	7	10	Gas
Sonat Sea Robin	1990	0	2	Gas

Source: Improving the Safety of Marine Pipelines

4. Pipeline Standards and Legislation

4.1 Introduction

Steel pipeline design and construction practices were originally developed in the United States in the early part of this century. The first pipeline codes were written by ANSI and became:

- ANSI³ B31.4 Liquid Petroleum Transportation;
- ANSI B31.8 Gas Transmission and Distribution Piping Systems.

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American National Standards Institute (ANSI)

The first British Standard, CP 2010, was published in 1970. When North Sea gas was discovered, British Gas regarded the existing standards as inadequate and developed their own standards through the Institution of Gas Engineers as IGE/TD/1 for methane only. In 1993 a new British Standard, BS 8010, was introduced which combined IGE/TD/1 and the best of the other international standards.

Design factor is an important concept in all pipeline codes. Design factor is the ratio between the operating (hoop) stress in the pipeline and its yield stress. Hoop stress is given by the formula:

$$\sigma_{\rm op} = \underline{pr}$$

where: $\sigma_{op} = \text{ operating stress}$

p = pressure

r = radius

t = wall thickness

Design factor =
$$\sigma_{on} / \sigma_{smvs} < 1$$

There are key differences between the way the existing codes treat oil and gas pipelines. In the existing American and British codes:

Oil pipelines

- No account is taken of population density in the location of pipelines.
- There is no specified minimum distance from occupied buildings.
- Pipelines can generally be built with a design factor of 0.72 in any location.

Gas pipelines

- Account is taken of population density.
- Minimum distance from occupied buildings is specified in the British Standards.

The design factor is as low as 0.3 in populated areas in British Standards, and 0.4 in American standards.

ANSI (now ASME⁴) B31.8 is the most widely used standard for gas pipelines, and the one from which most European standards originate.

• This standard applies to both transmission and distribution pipelines, without pressure limitation.

⁴ American Society of Mechanical Engineers (ASME)

- Wall thickness and design factor are determined in relation to population density.
- Proximity distances from occupied buildings are not limited.
- This standard does not refer to risk assessment.

The requirements of ASME B31.8 relating design factor to population are outlined in **Table 4**.

Table 4 Design factor requirements of ASME B31.8 by location type

Location class	Definition/description	Design factor at
		planning stage)
Class 1/Division 1	n/a	0.80
Class 1/Division 2	0-10 buildings, e.g. rural areas	0.72
Class 2	11-45 buildings, e.g. fringe areas	0.60
	around cities, towns, industrial areas	
Class 3	46 or more dwellings, e.g. suburban	0.50
	and schools, hospitals, etc.; buildings	
	must be less than four storeys	
Class 4	Areas where multi-storey buildings	0.40
	predominate	

In the UK, for all flammable and toxic gases at atmospheric pressure and temperature, BS 8010 specifies initial routing requirements for minimum building proximity distance and design factor, depending on the population density, which are based on the results of risk analyses. However, it allows relaxation of these prescriptive requirements with respect to design factor and proximity *if a risk assessment can demonstrate that the levels of safety are sufficient.* This is an important caveat, in that it allows for change taking into account the availability of better information, modelling, and actual pipeline operation management. It also allows for consideration of novel situations from first principles, rather than trying to apply the same prescription to all eventualities.

This caveat is particularly necessary in the case of BS 8010, as a very stringent lower design factor, 0.3, has been adopted for all gases. This is lower than the authors are aware of existing in any other country and could be regarded as an over-conservative interpretation of research data, dating from the time when the gas supply organisation in the UK was embarking upon the development of a large gas transmission network and the experience of large-diameter, high-pressure pipelines was limited around the world.

Risk assessment is explicit in the Netherlands Standard, NEN 3650, which restates the general Netherlands risk criteria for individual risk and places it in the context of pipelines in order to determine the building proximity distance (as a minimum, the distance to the 10⁻⁶/year risk level); this is discussed further in Section 7.2.1 below. Societal risk criteria are also applicable to pipelines in the Netherlands.

For offshore pipelines NEN 3650 stipulates maximum leak frequencies in different marine areas; the main driver for this is obviously marine pollution issues. However, care is required with this approach because pipeline leakage frequencies are usually derived from historical data for similar cases, and the

requirements of the Dutch standard are significantly more stringent than the observed frequencies in the North Sea.

In Switzerland, risk assessment is required for new pipeline projects under the pipeline legislation as amended by the Swiss ordinance on protection against major accidents. For such projects, criteria exist which are applied to a graphical representation of the risk in a so-called "W-A diagram" (see Figure 3, page 37). It differs from risk representations more usually encountered in that the x-axis is not the number of fatalities but a major accident index (maximum of 1), whose values relate to specific kinds/sizes of accidents and is not restricted to fatalities but includes, for example, environmental accidents. The y-axis is the frequency of these events. In common with other countries which apply risk criteria, there are three regions – unacceptable, acceptable, and an intermediate zone.

Many international standards and regulations share some common themes. These are, briefly:

- a minimum depth of burial, which may vary depending on the soil type and location in terms of third-party activity and population;
- a minimum distance to housing, though often this constitutes only a few metres of "easement";
- a requirement for a lower design factor in more populated regions;
- a pressure limit for some hazardous material pipelines in densely populated regions;
- a requirement for routine surveillance;

as:

• a requirement for a formal system of incident reporting.

In general, therefore, there is an implicit acknowledgement of some of the key issues in pipeline safety and the safeguarding of the public, which may be summarised as follows:

- The routing of pipelines should be controlled in the vicinity of residential populations.
- Where it is necessary to approach residential populations, the likelihood of major failure is reduced by providing extra protection or reducing the design factor (this generally translates into increasing the wall thickness, but the real situation is more complex than this, as discussed below).
- The main cause of failure of buried pipelines is third-party interference, so considerable effort is concentrated on reducing the likelihood of damage from this cause.
- Society's perception of an incident is that several people being killed at once is very much worse than the same number of people being killed in separate isolated incidents; this is an implicit acknowledgement of the issue of societal risk and risk aversion.

Many countries now have to address increasing problems regarding their onshore pipelines, such

- Pipelines which were originally routed in relatively unpopulated regions are now surrounded by development.
- Routes are required to be found for new pipelines in developed areas.

- Existing pipelines are required to be upgraded due to commercial pressures.
- National or state boundaries are required to be crossed.
- Decisions are required in respect of remediation or replacement of ageing pipelines.

Whilst risk assessment and management are to some degree implicit in the existing regulations, internationally there is now a major tendency towards making risk more explicit as a means of rationally analysing the kinds of problems listed above.

Several initiatives are under way internationally which will change the regulatory and standard-setting environment for operators towards a more goal- and risk-based approach and away from an entirely prescriptive approach. Those of which the authors are aware arise from the U.S., the UK, the EU, Canada and Australia. [Brief summaries of these changes are discussed below; however, the details were addressed by the country representatives themselves at the Workshop, either in formal presentations or during discussions.]

4.2 Summary of Some New Legislation

4.2.1 United States

In 1995 there were many initiatives in national pipeline safety, which resulted in the Pipeline Safety Act of 1995 (still under consideration by Congress at the time of writing). This represents a departure from the previous prescriptive code-based approach. Instead, the concept of risk management is being promoted. The US Department of Transportation, Office of Pipeline Safety (OPS) has established joint government/industry risk assessment quality teams for the natural gas supply and hazardous liquid pipeline industries, to develop guidelines for the use of risk management in pipeline safety including enforcement procedures.

The new Act focuses on two major changes: the introduction of the concepts of cost-benefit and of the need to manage risks. It also instructs the OPS to co-ordinate the demonstration of these concepts with volunteer participants, in order to test the practicability of the responsibilities of both the regulator and industry.

It seems that, thus far, the US concept of risk management is not that which would apply in countries where wholly quantified approaches are the norm, but rather involves a qualitative risk screening and prioritisation approach. A number of demonstration programmes are to be set up in the next year which will allow operators to explain how their approach to risk management will provide for at least as great a safety performance as the current prescriptive regulations.

It is anticipated that the demonstration programmes will last four years. It is intended that project teams will be set up consisting of the operator and federal and state regulators, who will maintain responsibility for the demonstration projects throughout. One important aspect is that the OPS will support the operator if there are any subsequent liability claims, a vital issue in the US's litigious environment. The demonstration programmes may vary considerably in scope: they may cover an operator's whole network, a specific problem pipeline, or a particular issue of concern. It is clear that some operators (e.g. Chevron) are taking a very quantified approach, including the use of safety cost- benefit and the cost to avert the loss of life.

4.2.2 United Kingdom

The Pipeline Safety Regulations came into force in April 1996, though not all the requirements needed to be in place by that date. In general, the regulations do not make many new demands on pipeline operators, but they do bring into one document some previously piecemeal requirements for onshore pipelines. They also include offshore pipelines. As with all UK HSE requirements in the safety arena, there is a requirement to manage safety and risks to a level which is "as low as reasonably practicable", the so-called "ALARP" principle. (see **Figure 2**, page 35). The HSE continues to give advice to local authorities (local government) planning departments concerning granting permission for development close to major hazard pipelines in their area (as with any major hazard facility) and initial routing.

The primary new features of the regulations for major hazard pipelines are:

- the requirement for a Major Accident Prevention Document (MAPD) and documented safety management systems. These do not need to be formally submitted to the HSE, but must be available for inspection;
- the requirement for local authorities to prepare and maintain emergency plans in their area (and to co-ordinate with adjacent authorities);
- the enabling of the HSE to take action against third parties whose activities may threaten the integrity of a pipeline;
- the inclusion of natural gas (methane) pipelines. These were previously excluded, as the public gas supply was the responsibility of a publicly owned company (British Gas) which had special arrangements for routing and planning under the Gas Act. However, with the opening up of the gas supply business to competition, these special arrangements were no longer appropriate and so have been brought into the general requirements.

4.2.3 European Union

The difficulty of including distributed risk sources such as pipelines in major hazard legislation led to their exclusion from both the original "Seveso" Directive and its revision, the Seveso II Directive for Major Accident Hazards. However, the control of major accident hazards associated with pipelines was a subject of much debate during the drafting of the Seveso II Directive.

As a result, the Council has requested that the Commission develop proposals for pipelines. Consequently there is a study under way (of which this Workshop is a component) to review current industry practice in Member States, the role of national and international standards, and Member States' regulatory regimes in this area. This gathering of facts will assist the Commission in its development of any future proposals for major hazard pipelines.

4.2.4 Canada

In Canada, the CSA⁵ Z662 ("Oil and Gas Pipeline Systems") standard addresses the design, construction, operation and maintenance of oil and gas pipelines. This standard is very similar to US standards, and therefore does not currently address risk assessment or risk management issues. However,

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⁵ Canadian Standards Association (CSA)

CSA has established two task forces, one with a mandate to develop a risk-based standard for pipelines and the other to develop a risk assessment guideline for the 1996 version of the Z662 pipeline standard.

In support of this, a Pipeline Risk Assessment Steering Committee (PRASC) was formed early in 1994 to provide leadership and to co-ordinate the various initiatives and programmes to support a staged implementation of risk assessment and management principles. It is working closely with the Z662 committee. The goal of this staged implementation is that, by the year 2000, the CSA standard will be accepted by industry and possibly adopted into legislation.

4.2.5 Australia

Gas and liquid pipelines operating at pressures above 1050 kPa are currently designed and constructed to an Australian standard, AS2885. However, this standard is being rewritten and will include the introduction of a requirement to assess risks to and from the community and take appropriate action.

The new pipeline standard will include the concepts of both qualitative and quantitative risk assessment, but will provide for a fully quantified approach, analogous to fixed facilities only where warranted. Due to perceived problems of land sterilisation or excessive cost to pipeline operators, the inclusion of separation distances has been actively resisted to date, though this is the preferred route of some state regulators. However, there is some support for the concept of "consultation distances" for land use planning purposes, i.e. distances which merit that a more detailed analysis of the risks is carried out rather than a prescriptive "no-go" region.

Much of the debate revolves around land use planning issues, in common with elsewhere in the world. These issues are discussed further below.

5. Risk Assessment

Given the move towards more explicit risk assessment, whether quantitative or not, in this section risk assessment and how it can be used as an aid to safe design, routing and operation are discussed in more detail.

5.1 Introduction

Risk assessment may be implicit or explicit, and qualitative or quantitative. Historically, design rules and standards were wholly deterministic in their approach in order to ensure safe and efficient design and operation, with no explicit reference to risk assessment. In many countries this is still the case, for example in Germany and France. However, it could be argued that some degree of risk assessment was implicit in these codes, if only through requiring the judgement and experience of the authors in setting the deterministic values.

Increasingly, risk and probabilistic assessment is being introduced into design codes and related legislation, both in terms of addressing safety issues and in the limit state design approach to reliability, i.e. the approach of designing components and systems taking account of their engineering performance in a predictive fashion rather than using prescriptive factors to determine the main design parameters.

Risk assessment need not always be a complex, highly quantified process. The application for which it is required may not always require this. For example, for prioritisation purposes, or at a simple

screening level, a risk ranking approach based on a simple matrix may be adequate. In this process the likelihood of a hazardous event and, similarly, the severity of the outcome may be ranked on a scale of, say, 1 to 5. The risk is then the product of these two values, thus allowing the events to be ranked according to risk.

However, where criteria exist which require evidence that a facility or pipeline is below some upper level of risk, a fully quantified risk assessment is required. Also, if a rigorous cost-benefit analysis is to be carried out, then the risks must be quantified as accurately as possible. Risk assessment may also be used as a tool in determining the priorities for maintenance or the optimum remedial approach for ageing pipelines, e.g. increased or intelligent inspection vs. selective replacement.

5.2 An Overview of Quantified Risk Assessment (QRA)

5.2.1 Background

The issues surrounding whether high-pressure hazardous pipelines should be located in populated areas have given rise to considerable discussion by regulators, designers and operators ever since pipelines were first constructed. As far as the location of pipelines in populated areas is concerned, we are basically faced with three choices.

The first choice is to design and build a pipeline in such a way as to try to virtually eliminate the chance of failure, for example by installing heavy wall pipe, but to allow the pipeline to be constructed close to populated areas. If this approach were followed, it is necessary to recognise that pipeline failures are almost impossible to eliminate and that the consequences of a failure in a heavily populated area would be serious.

The second choice is to build a pipeline in a location so far away from populated areas that the consequences of failure cannot affect any populations. If this approach were followed, it is necessary to recognise that many countries are so densely populated that it would be difficult to find areas where pipelines could be constructed and be practical.

The third choice is to compromise and use a "risk-based" approach to the siting of pipelines near populated areas. In this case "risk" is measured to determine a tolerable degree of acceptability between the likelihood of pipeline failure and the consequences faced by populations living near to pipelines in the event of failure. In this approach it is accepted that pipelines fail (although account can be taken of design methods to reduce the chance of failure) and that populations will be located in areas where they can be exposed to the consequences of pipeline failure.

One such "risk-based" approach is Quantified Risk Assessment (QRA). QRA is a method of obtaining a measure of performance with respect to a given safety standard or objective. It has been primarily developed as a tool to assess large-scale accidents, which by their very nature are rare, and whose frequency of occurrence and consequence cannot therefore be obtained from statistics alone. The QRA technique is in widespread use in the onshore and offshore oil, gas and chemical, transport and nuclear industries, being applied in the areas of conceptual design, siting, official approval, detailed design and safety reappraisal.

Unfortunately, the word "risk" means many things to many people, and a definition of terms used in QRA is needed to minimise confusion and facilitate communications, for example between countries.

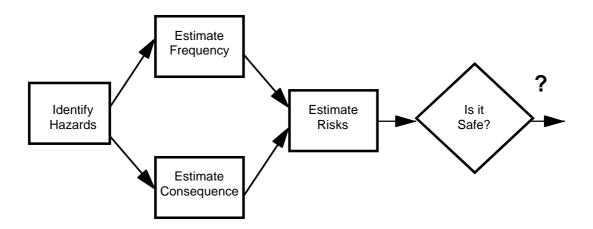
5.2.2 Classical QRA Methodology

The classical approach to QRA is shown in **Figure 1** (next page). This technique is the most comprehensive type of safety analysis.

The main sequential stages of this approach are as follows:

- *Hazard and failure identification*. The objective of this process is to identify all of the failure cases.
- Frequency estimation. Failure or initiating event frequencies are usually estimated from historical failure rate data for pipelines. These initiating events are developed into a larger set of outcomes via event trees, with distinct consequences which can be evaluated in terms of effects.
- Consequence analysis. This means using theoretical models of chains of events, such as discharge of hazardous materials, dispersion in the air, ignition, explosion (where relevant), fire and so on. A large range of well-tested models exists for this purpose. These consider the rate of release of a hazardous material, the extent of its effect in terms of thermal radiation or toxic concentration, and the probability of fatalities or pollution at a particular location.
- *Risk summation and evaluation.* This step involves summing the likelihood and consequence information derived in Steps 2 and 3 above and expressing the total risk in a form which suits the decision-making process which the QRA will support.

Figure 1 Schematic of Quantified Risk Assessment



A particularly important aspect of onshore pipeline risk assessment is the analysis of relevant historical data on leakage incidents to derive leak frequencies. Where data on leakage incidents exist, there may be very little information, in particular, on the size of the leak in terms of hole size (as opposed to barrels of oil spilled or cost of damage). Additionally, information on cause may be wrongly interpreted in the field. As onshore flammable pipeline risk is driven by the frequency of major failures, good data sources are essential if the risk assessment is to be realistic. Information may also be obtained from the historical record for ignition probabilities.

The main sources of data for onshore pipelines are:

- The European Gas Pipeline Incident Data Group (EGIG)
 - data from gas transmission pipelines in Belgium, France, Germany, Italy, the Netherlands and the UK
- CONCAWE (the oil companies' European organisation for environment, health and safety)
 - European liquid line data.
- US Department of Transportation Office of Pipeline Safety (US DOT, OPS)
 - data on US gas transmission lines. Care must be exercised in its interpretation due to a change in reporting requirements in 1984.
- US liquid line data is also available from the US DOT, OPS.

For offshore pipelines, North Sea data are collected by UKOOA (the UK Offshore Operators Association) and then published by the HSE. There have been two such publications in recent years

(since Piper Alpha). They are frequently referred to as the PARLOC data (Pipelines and Risers, Loss of Containment).

In the US, data are collected and published by the Minerals Management Service (MMS) and the US Coast Guard. Several states also collect data; California has its own detailed records, some of which were published recently by the California Fire Marshal's Office.

5.3 Measures of Risk

In order to judge safety performance in terms of risk, it is necessary to measure it. There are two broad categories: individual risk, and societal risk.

5.3.1 Individual Risk

Individual risk (IR) expresses the risk of death or serious injury (in the UK, the HSE use a concept called "dangerous dose") per year of exposure to an individual at a distance away from the hazard source, usually in the form of iso-risk contours.

In the case of pipelines, initially this is usually represented as individual risk transects along the whole route. These are generalised representations of the individual risk at distances perpendicular to a linear development, such as a pipeline or other transport route. They are a very useful representation of the risk of pipelines, particularly at the route-planning stage. Where a route subsequently becomes defined as running close to a town or any other features of particular interest, individual risk contours for that location may be calculated for greater accuracy.

5.3.2 Societal Risk

Societal risk considers the risk of death from an installation or activity to society as a whole. A number of measures or representations of societal risk are possible; the most commonly used are the Societal Risk or FN curve, and the Potential Loss of Life (PLL). The measurement and representation of societal risk is important, as it distinguishes between frequent smaller events and those events which have the potential to kill or injure many people at the same time. This allows the public's aversion to large accidents to be reflected, as appropriate.

Societal risk is particularly important when the assessment of risk to real communities is an issue, so that areas of high population density along a pipeline route, whether temporary (e.g. a sports stadium) or permanent, need to have this further calculation carried out. Societal risk calculation should reflect as accurately as possible the *real* situation in terms of the actual nature and distribution of the population, the nature of the housing, the ability of people to evacuate, ignition sources (e.g. busy roads/railways), and actual weather conditions.

The individual risk from a pipeline is typically low, and is only significant when large numbers of people may be affected by the same incident. This is often recognised implicitly in pipeline codes, where more stringent requirements exist for higher population densities.

5.4 Offshore Pipeline Risk Assessment

The approach to risk assessment offshore is no different in terms of its basic methodology, but the importance of various aspects of the analysis differs.

In the case of onshore gas pipelines, only major releases contribute significantly to the risk, due to their relative distance from the majority of the population. Reducing the consequences by, for example, reducing the valve spacing cannot be achieved to any significant extent onshore; however, such is not the case for offshore pipelines close to platforms, where lengths of the order of tens of metres may be isolated. This was the approach taken in the UK following the Piper Alpha disaster, with the retrofitting of top-of-riser and sub-sea emergency shutdown valves, and this has now become a widely adopted international practice. Reducing the inventories which may become involved allows those on board away from the immediate incident to take shelter until the available flammable material has been consumed. Offshore pipeline risk reduction is therefore much more strongly dominated by consequence reduction as opposed to frequency reduction.

As stated earlier, human safety is not normally a primary explicit consideration for offshore pipelines except near offshore platforms or at landfalls. In the former case, safety aspects are most often dealt with within, say, 500 metres of the platform through safety analysis of the offshore platform itself. That is not to say that the general regulations which govern pipelines' design and operation do not implicitly affect safety by ensuring that pipeline integrity is maintained and that appropriate emergency shutdown valves are provided. However, the impact on life in terms of risk lies within the scope of ensuring the safe operation of the platform.

Landfalls are effectively the start of onshore sections of pipeline, and their safety may therefore be assessed in the same manner.

In the case of open sea sections of offshore pipelines, the focus is therefore on reducing the risk of pipeline damage due to anchor and fishing damage, buckling and corrosion, in order to maintain the reliability of pipeline and limit pollution. The Netherlands Standard sets out criteria for allowable leakage frequency of pipelines, both in the open sea and close to shore. However, as these are significantly below those currently observed in the North Sea, the appropriateness of these numbers is open to question.

In Norway, which has in recent years constructed and operated major transnational pipelines to Europe in the North Sea, such as Zeepipe, a major study has been under way to investigate the issues which affect the integrity of pipelines.

5.5 Risks to the Environment

There is often a different emphasis in considering risks to the environment, as opposed to public safety, in that it is predominantly major releases in populated areas which cause concern in terms of safety whereas, when considering environmental risk, it may instead be the relatively small, difficult to detect leak in a remote and therefore inaccessible region which is the biggest risk contributor. Inaccessibility may be important for different reasons; for example, remote regions will tend to be those which are relatively unspoilt in terms of habitat and wildlife, and will also be the most difficult and expensive in which to implement an effective clean-up programme. Moreover, in terms of environmental damage, liquid lines are of much greater concern than natural gas pipelines, whereas the reverse is generally true for safety.

For submarine pipelines, the issue of slow corrosion or minor impact damage leaks causing pollution is well-known and receives attention in the literature and in legislation (upper bounds of leakage frequency in the Netherlands Standard, for example), but of greater concern perhaps is the potential for groundwater contamination from onshore liquid pipelines.

Of course, the general principles which ensure pipeline integrity, and thus limit loss of containment, apply equally to safety and environmental considerations. Engineering to date has been prioritised with respect to major releases, on both safety and economic grounds, and many of the leak detection systems in place may not be able to detect small leaks quickly. The overall quality of pipeline management therefore has an increased importance for environmental purposes, in ensuring that particularly sensitive areas are monitored closely and that routine surveillance, whether aerial or on the ground, will improve the probability of early detection.

Attempts have been made to quantify environmental risk from pipelines in terms of the amount of environmental liability per km-year. This has been difficult due to problems associated with quantifying environmental damage and liability costs.

6. Measurement and Acceptability of Risk – Criteria

6.1 Individual Risk

Many countries, including Australia, the Netherlands and the UK, employ numerical criteria in judging tolerability or acceptability in terms of safety. Such criteria are also used in Hong Kong. One approach is to set an upper limit of tolerability beyond which one must not go and a lower limit of negligible risk; in between is a grey area where risk reduction measures must be considered and discussed on the grounds of reasonableness and cost-benefit. The Netherlands only uses an upper limit of tolerability beyond which one is not allowed to go, except on rare occasions and on the basis of a decision of the minister(s) responsible for the risk policy. Lower levels of risk can be applied by the competent authorities on the basis of ALARA (as low as reasonably achievable), to be compared with ALARP in the UK, but with a somewhat stronger accent on best available technology. No negligible risk values used in this policy.

The US is also moving to a more risk management/cost-benefit oriented approach. In a recent study on the safety of marine pipelines, the National Research Council proposed upper limits of individual risk of 10⁻⁴ to 10⁻⁵/year, with the "*de minimis*" being set at 10⁻⁷/year and, in between, a figure of \$20 per capita per year to avoid a risk of 10⁻⁵/year. In addition, the OPS quoted a figure of \$2.7 million to avert the loss of a life recently (Risk Management and the Pipeline Industry Conference, Houston, April 1996).

This is similar to the principle and the risk levels applied to hazardous industries in the UK and which may be summarised by the ALARP triangle, as shown in **Figure 2** (next page). ALARP stands for "As Low As Reasonably Practicable". As used in the UK, it is a region between that which is intolerable, at 10^4 /year, and a broadly acceptable level of 10^6 /year, with a further lower level of risk of $3x10^7$ /year being applied to either vulnerable or very large populations for land use planning.

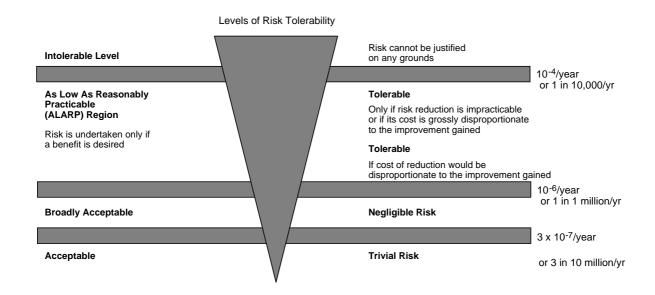


Figure 2 The ALARP triangle (as used in the UK)

These land use planning risk criteria are currently being revised in the UK and do not formally apply to pipelines. However, the same principles apply to the judgement of risk from pipelines, with the additional requirement in the UK and the Netherlands of a minimum proximity distance from buildings. This approach is also being discussed, and looks likely to be adopted, in Australia.

6.2 Societal Risk

Compliance with individual risk criteria is a necessary but not always sufficient condition. Even if it were satisfied, societal risk would also have to be examined in some circumstances. Societal risk is the risk of widespread or large-scale harm from a potential hazard, the implication being that the consequences would be on such a scale as to provoke a major social or political response and therefore may lead to public discussion of regulation in general or, as in the Netherlands, to analysing the societal risk per kilometre of a transport route.

Whilst there are no formal criteria to judge the acceptability of societal risk in the UK at present, these criteria do exist in the Netherlands. In the UK, the ACDS Committee on Transportation of Dangerous Substances put forward tentative societal risk criteria (based on fatalities, not dangerous dose) for communities in the vicinity of ports and marine terminals handling dangerous goods. Societal risks are well-established in the Netherlands for fixed installations and are now applied to pipelines.

Societal risk is a particularly difficult concept in the context of pipelines or transportation route, as the risk is distributed along the whole length of a route with different populations being involved. If societal risk is considered, it is most commonly considered for discrete communities, or using uniform population densities. It is, however, of considerable importance for major hazard pipelines, where individual risk levels are generally very low and it is the risk of a major accident which is the primary driver.

As mentioned earlier, the Swiss Government has developed societal risk criteria which are applied to pipelines in the form of a WA diagram; this is illustrated in **Figure 3** (next page). In the UK, simplified methods of measuring societal risk in terms of a risk integral, which takes account of the population at risk, their vulnerability, and occupancy, are currently being discussed as a possible pseudo-societal risk measure.

6.3 Accuracy

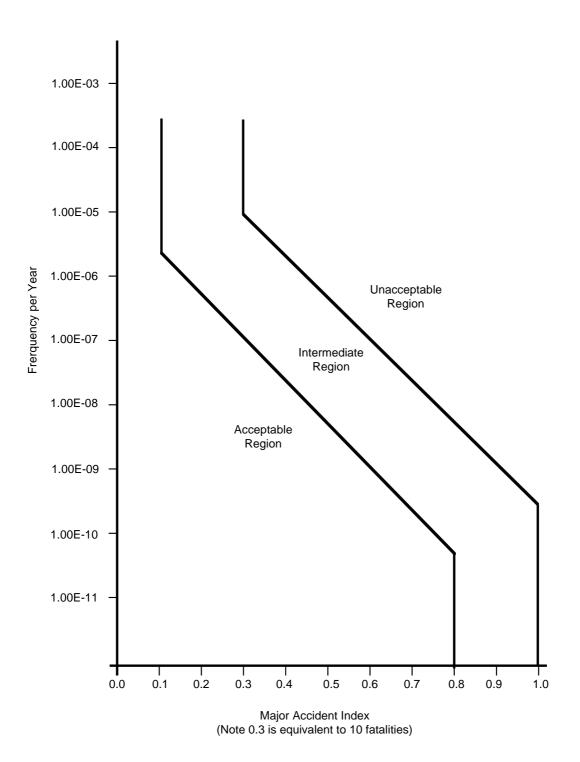
Risk calculations are not precise. Their accuracy is determined by the quality of base data and expert judgements. Despite the data published by EGIG, CONCAWE and others, considerable discussion has taken place on the need to improve the consistency and range of failure data sources for pipelines. It is our view that an international pipelines failure database should be set up, using a consistent reporting system to ensure reliability of data. At a minimum, the data collected should cover diameter, wall thickness, substance conveyed, failure cause, release hole size, whether release ignited, volume of material lost, consequences (fatalities), suburban or rural location, and age.

It should also be recognised that where individual risk or societal risk acceptability criteria have been published, the differences between wholly unacceptable and wholly acceptable levels of risk are often as much as two orders of magnitude. This would indicate that the need for greater accuracy of calculation should only be considered in the context of the wide bounds of risk acceptability – in other words, the pursuit of accuracy beyond a certain point does not always gain a great deal in terms of the ability to make decisions.

This again shows the danger of using risk assessment as an absolute measure – risk assessment is at it best when comparing different alternatives or identifying the major contributors to risk.

Where risk assessment is used to determine absolute levels of risk, the results should be regarded as providing a logical background for informed decision-making – thus giving better guidance to decision-makers than would be available if personal judgement alone were used.

Figure 3 The Swiss frequency-consequences diagram (the "WA" diagram)



7. Risk Reduction Measures

7.1 Prevention – Frequency Reduction

By far the major contributor to the risk to life from an onshore gas pipeline is the full-bore rupture of the line, even if its relative frequency of occurrence is low. The consequences of such a release in terms of injury to the public cannot be influenced significantly, since the time it takes a gas cloud to develop its full extent is of the order of less than a minute, much faster than the closure time of most valves even if detection were instantaneous. It is therefore important to note, for pipelines of this kind, that closer valve spacing is of no benefit to human safety; on the contrary, valves represent an additional leak source.

Similar arguments apply to flammable liquid pipelines in terms of human safety – although in a less marked fashion – and also, crucially, to liquid lines, for which valve spacing is an important factor in reducing environmental damage.

For pipelines conveying toxic substances, the duration of release, and therefore valve spacing, become critical for human safety.

In regard to the human safety aspects of gas and flammable liquid pipelines, given the difficulty of reducing the consequences, the emphasis in risk reduction must be on reducing the frequency of full-bore failure. There are two considerations in approaching this:

- recognising the importance of external impact (typically the cause of 50 per cent of all failures); and/or
- reducing the frequency of slow-growing defects becoming full-bore failures by ensuring that
 mechanical conditions apply such that defects always grow through the wall first and leak,
 rather than developing along the pipe and creating a rupture, the so-called "leak before break"
 regime.

The ways these considerations may be incorporated into a risk analysis are discussed below.

7.1.1 External Impact Protection

There are three common ways of achieving additional impact protection which may be incorporated in a quantified way in a risk assessment: greater wall thickness, deeper burial, and physical protection.

In the case of wall thickness, work by British Gas found that no holes greater than 80 mm could be caused by excavators of a size which would not be identified by routine inspection in pipelines with a wall thickness of greater than 11.91 mm, and this reduces to 9.1 mm if the pipeline is operating at a design factor of 0.3. Therefore, with these wall thicknesses (depending on the conditions) the frequency of failure due to impact can be significantly reduced: 10 per cent of the normal value has been used in some assessments. A similar situation has historically been deemed to apply to physical protection by concrete slabs. However, some recent work by British Gas showed that for slabbing to be effective, it must be accompanied by clear visual warnings by means of coloured tape or similar material.

Burial of the pipeline two or three metres deep is also an effective method of reducing the frequency of external impact, which can be reflected properly in the derivation of figures in a risk assessment.

This approach applies equally to oil and gas pipelines, as it is a matter of physical protection of the pipeline from damage.

7.1.2 Leak Before Break

Much of the work on this aspect of pipeline behaviour was carried out by Battelle in the US in the 1960s-1970s and continued by British Gas (BGC) in the UK in the 1970s. The aim of the work was to ensure that pipelines operated in a regime where failure occurred through the wall thickness, i.e. a leak formed, rather than propagating along the pipe to eventually produce a large rupture, following some spectacular failures of pipelines in such a manner.

In summary, it was found that, at design factors of 0.3 and below, the failure of a flaw would always be in the through-thickness direction, i.e. it would leak rather than propagating along the pipeline's length to a major rupture. This led to the advice in the UK standard, BS 8010, to adopt the conservative value of 0.3 at residential locations. It is conservative in that the original work presents data for both the kind of sharp defects introduced by laboratory machining and the kind of profile expected from, say, corrosion or material defect flaws. In the latter case, the more appropriate design factor threshold was found to be 0.4. However, the British Standard allows relaxation of these requirements provided a risk assessment can prove otherwise.

Lower design factors may be achieved in two ways: higher grade steel, and greater wall thickness. The choice of approach will influence the risk analysis, and may therefore affect the pipeline designer's freedom to choose, depending on the route planning implications.

Higher grade steel

If a pipeline is in the leak before break regime (which is nominally 0.3 or 0.4, but may be argued to be 0.5 for larger, heavy-walled, pipelines), then it may be argued that rupture from slow-growing defects, i.e. from corrosion or inherent defects, is not possible and that therefore the failure frequency for ruptures may be attributed to the largest hole size category. However, the rupture frequencies from external impact and ground movement or other natural hazards remain unchanged.

Greater wall thickness

The same comments as for higher-grade steel apply, but additionally so do the reductions afforded by greater wall thickness discussed earlier. This means that the frequency of ruptures, if a low design factor is achieved in this way, is reduced to a very low level.

The same arguments apply if a low design factor achieved by whatever means is applied in combination with any of the physical protective measures, such as concrete slabbing or deeper burial, discussed above, i.e. the effects are additive.

7.1.3 One-call Systems

These aim to reduce the frequency of damage due to third-party activity by providing a centralised system for imparting information on the locations of pipelines to utilities and other parties who may need to excavate in the area prior to the commencement of the work.

In the Netherlands and in many US states, these systems are legally required. In other places they are good practice, but voluntary, arrangements. In the UK there are some collaborative arrangements between pipeline operators, but no national system exists. Pipeline operators would like to see this being championed by the HSE.

There is some evidence from the US that one-call systems do indeed have a beneficial effect on the reduction of third-party damage, and therefore on the overall failure rate of pipelines, given the importance of this failure mode.

7.1.4 Intelligent (or Smart) Pigs

Intelligent pigs are making a major contribution to reducing pipeline failure rates from corrosion and time-related failures originating from inherent material defects or construction damage. One of the problems often encountered by the users of intelligent pigs is the variation in standards of performance by pigs produced by a variety of manufacturers. There has been a call for a minimum performance standard test for all such devices, to assure operators and regulators that defects can be accurately described with consistency.

7.1.5 Other Monitoring Methods

In addition to the above, there are also many other monitoring methods currently in use whose efficacy is being continuously improved. These include aerial surveillance, patrolling on foot, leak detection and corrosion monitoring systems, and close liaison with the population along the route.

7.2 Risk Mitigation Methods

Other means of risk reduction concentrate on reducing the exposure of the population to the risk source. This may be achieved either by ensuring that, as far as possible, pipelines are not routed through densely populated regions, or through efficient and effective emergency response once an incident has occurred.

7.2.1 Land Use Planning

We have seen in the discussion on regulation of pipelines that land use planning in the vicinity of pipelines is implicit in much of the design and routing advice. Thus, as far as possible, pipelines are kept away from populated areas and, where this cannot be avoided, more stringent design criteria are applied in the form of a lower design factor and/or thicker walls. In most countries high-pressure pipelines (above 7 bar) are not permitted in very densely populated areas, such as cities.

However, whilst this might be possible with a new pipeline in a greenfield site, over time the pressure on development around the pipeline may become intense and some buildings may change their use. There is then a need to assess the risks posed by the pipeline to the new development, in order to determine whether or not it should be permitted. In the UK this is done by considering the nature of the

development in terms of the number of people, the proportion of time occupied, and the vulnerability of the population. The risk requirements become more stringent according to the increasing "sensitivity" of the development. These are currently being revised, but, broadly speaking, **Table 5** summarises the nature of the distinct developments and the level of tolerable risk.

In the Netherlands, a limiting value for the individual risk (IR) of 10^{-6} /year applies in the case of new planning situations. It is possible to deviate from this value on the basis of an integrated weighing of interests, presented to the responsible ministers for approval. The aim for existing situations with an IR exceeding 10^{-6} per year is to reduce the IR to the set criterion along the perimeter of vulnerable functions. There is no negligible risk value stated in this policy. The provisional SR value per km of route has been determined at 10^{-4} per year for ten fatalities, 10^{-6} per year for 100 fatalities, and so on. A local authority can deviate if properly motivated. For effects on zoning, see page 20 of *Risk-Criteria for the Transport of Hazardous Substances* (The Hague, 1996).

Table 5 Land use planning: UK Health and Safety Executive (HSE) risk criteria

Category	Type of population	HSE suggested individual risk level x 10 ^{-6/} year
A	Residential housing including hotels	
	a) greater than 25 peopleb) greater than 75 people	10 1
В	Factories, offices, car parks, etc. – less than 100 occupants	No maximum risk level specified, but assumed that risk of injury from major hazard is substantially less than risk of occupational injury, i.e. less than 23
С	Retail, community, leisure, etc. or housing with less than 10 units	No specific criteria given; probably of the same order as Category A
D	Highly vulnerable or very large facilities, e.g. schools, hospitals, more than 1000 people outdoors	0.3

In Australia, as part of the discussions relating to the new standard, a working group of state planners (Hazardous Industry Planning Task Force, HIPTF) has been set up to develop the establishment of QRA-based guideline separation distances between gas pipelines and urban development. The industry, through the APIA (Australian Pipeline Industry Association), is working with the HIPTF to agree the approach and methodologies. As discussed earlier, a particularly important issue is the concept of "consultation distance" vs. "separation distance", where consultation distance refers to some rationally determined distance within which developers must consult with planning authorities and the pipeline operators, and where detailed QRA may be required to assess the risks locally.

7.2.2 Emergency Planning

Emergency response plans exist to some extent in all areas of the developed world, it would seem. However, their status and completeness vary for example as to whether paper plans and desk exercises only are required, or actual physical demonstration of capabilities.

Emergency response clearly relates to the reduction of risk through reducing the consequences in terms of human injury or pollution effects.

It could be argued that active response by the emergency services is most relevant in the case of releases of toxic materials or flammable liquids, where the length of time the public is exposed to the hazard will materially affect the risk. However, for flammable gases the emergency response may be too slow to avoid the population being affected, for the reasons discussed earlier. The response therefore becomes a question of prompt medical attention.

An important aspect of any emergency response plan is the communication of the appropriate action to be taken to the public. A public education and communication programme should therefore be a crucial feature in the success of such a plan. This may not be practical along the whole length of a major cross-country pipeline, but may be appropriate for discrete communities close to a pipeline route, or where development has led to significant encroachment.

In the case of environmental pollution, an assessment of the environmental risks along the route, together with a classification of habitats, can lead to a rational prioritisation of the positioning of response and intervention points in the event of a pollution incident.

Of key importance is the establishment of a good liaison between the operator, the community and the local authorities, such that the lines of communication and responsibility are well-understood in the event of an incident. In areas where several large companies are co-located, the arrangements between local officials and their emergency response plans, and those of the companies, need to be particularly well-co-ordinated and well-developed. As an example, there should be direct hot-lines to emergency services. However, the same degree of preparation may not be necessary for an area with a single pipeline crossing a sparsely populated region, as the relative infrequency of pipeline accidents would not warrant limited local resources being spent excessively.

7.3 Safety Management

An area whose importance is often underestimated when considering the risk of land pipelines is safety management. Clearly how a pipeline is managed when it is in operation is an important factor in maintaining its integrity, and therefore safety, and in determining the response to an incident. Effective safety management therefore has the ability to influence both the likelihood and consequence components of risk.

Safety (and environmental) management should be an integral part of the normal business management of a pipeline operator. An effective safety management system should detail clear lines of responsibility and accountability for health and safety from the highest management down. The line of command and accountability may change during the life cycle of a pipeline; the management of this change should be set out in the safety management system.

Some critical areas which should be addressed are:

- ensuring that there are systems for co-ordination of all those involved in the safety of the pipeline;
- establishing operating procedures for normal as well as abnormal operation;
- communication of those procedures to relevant personnel;
- establishment of adequate systems for selection control and for monitoring the performance of connectors;
- establishment of standards for training those with a significant safety role, from the highest management to operators;
- procedures for systematic review of the hazards;
- procedures for planning modification;
- procedures and records for inspection, testing, and quality assurance;
- specific arrangements for dealing with emergencies.

An important aspect of effective safety management is also the setting up of public liaison and awareness systems, and personal contact points for the public. As with all management systems, their performance must also be audited periodically.

It is undoubtedly the case that the "responsible care" approach adopted by the majority of pipeline operators in the industry achieve these broad goals of safety management.

The industry's approach is to create high-quality pipelines at the outset to recognised codes and standards, and then ensure their continued integrity.

One example of a safety management system in use in the industry is PIMS ("Pipeline Integrity Management Systems"), which has the following key elements:

- clear objectives and policies;
- a suitable organisation with clear definitions of asset ownership;
- clearly defined responsibilities and staff competencies;
- adequate standards and procedures;
- performance monitoring;
- suitable audit/review procedures.

Different companies implement PIMS in different ways.

A major component of any safety management system should also be the recognition of the importance of third-party damage in pipeline failure, and the taking of all reasonable steps to prevent this as far as is practicable, e.g. by informing inhabitants, instituting one-call systems, etc.

8. Issues Discussed during the Workshop, with Some Conclusions

The previous sections discussed many aspects of pipeline safety, and some key issues were presented to the Workshop for discussion. We have attempted to treat the issues briefly as follows, as an indication of the consensus reached during the Workshop:

• What constitutes a major hazard pipeline?

Answer: A major hazard pipeline is a pipeline containing flammable and/or toxic fluid or gas with the potential to cause significant loss of life.

• Is a risk-based, goal-setting approach the most appropriate way to ensure the safe operation of pipelines?

Answer: A risk-based, goal-setting approach is an appropriate way, along with other methods, of ensuring that pipelines can be operated in a manner which reduces risk to people and the environment to a level which is as low as reasonably practicable.

• How are the societal risk aspects best addressed, and should these be the main criteria for detailed assessment?

Answer: Societal risk aspects are best addressed by the production of an FN curve or similar representation, but this should not be the only means by which risk can be assessed.

• What pipeline accident data sources are available?

Answer: Many pipeline accident data sources are available, but the data from them are variable in quality, variable in the data reported, and selective in regard to the accidents reported.

• How can the quality of accident data be improved and pooled internationally?

Answer: We recommend the setting up of an international pipeline accident database with defined and consistent world-wide data collection.

• How can the results of data collection be disseminated and used to drive safety requirements?

Answer: Data can be analysed and trends evaluated, and they can also be used as a basis for establishing risk levels as part of the process of Quantified Risk Assessment.

• What information is there on the interaction of design factor/wall thickness and material strength in relation to pipeline failure?

Answer: Research is available from a number of sources on design factor/wall thickness and material strength and its relation to theoretical pipeline failure, but little evidence is available to correlate this directly to real accidents.

• What are the best measures for preventing third-party damage – for example, one-call systems? surveillance? physical protection?

Answer: All the above.

• What constitutes "good" safety management in a pipeline system?

Answer: Good safety management includes a precise Environmental, Health and Safety (EHS) policy, a clear identification of risk and means of control, an emergency plan, EHS responsibilities clearly defined at all levels in the organisation, a system of auditing to ensure that the system is working correctly, and effective monitoring of performance and review.

• How can environmental risks be minimised?

Answer: Environmental risks can be minimised by reducing the chance of failure of the pipeline through incorporating risk mitigation measures in the design of pipelines at sensitive locations, routing pipelines away from environmentally sensitive areas, and installing leak detection systems capable of identifying small leaks.

• How should emergency response plans best be drawn up and co-ordinated with the community and its authorities?

Answer: Emergency response plans should best be drawn up in direct consultation between the pipeline operator, the authorities and the community.

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