DET NORSKE VERITAS

PIPELINE ABANDONMENT SCOPING STUDY

NATIONAL ENERGY BOARD (NEB)

Report No.: EP028844
Reg No.: ENACA855
November 2010

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EXECUTIVE SUMMARY

Det Norske Veritas (DNV) together with TERA ENVIRONMENTAL CONSULTANTS and BGC ENGINEERING INC. were contracted by the National Energy Board (NEB) to conduct a literature review regarding the current understanding worldwide with respect to the physical/technical issues associated with onshore pipeline abandonment and use the results of the literature review to critically analyze and identify gaps in current knowledge, and make recommendations as to potential future research projects that could help to fill those gaps.

The project team conducted the literature review based on more than 100 key words applicable to pipeline abandonment. Various combinations of these key words were used to search for published information dealing with issues associated with pipeline abandonment. More than 430 abstracts of published papers were reviewed and these were narrowed down to 83 relevant documents, which were obtained for more detailed reviews by the subject matter experts (SMEs). In addition, various standards from North America, South America, Australia, Europe, and the United Kingdom were reviewed for requirements specific to pipeline abandonment.

Based on the review of these documents by the SMEs, this report outlines the current level of knowledge regarding issues related to pipeline abandonment; identifies the knowledge gaps and, in Section 5, outlines additional research topics that could be completed in order to address the knowledge gaps. Topics recommended for additional study include:

Recommended Study	Estimated Cost
Detection of Residual Contamination	$140,000
Risk Assessment	$50,000
Decomposition of Pipe Materials	$25,000
Cleaning Methods and Disposal of Cleaning Fluids	$200,000
Abandonment under Water Bodies	$350,000
Pipeline Exposure Data from Existing Records	$50,000
Buoyancy Effects on Pipeline Exposure	$75,000
Standard Pipeline Products List	$25,000
Frost Heave Effects on Pipeline Exposure	$50,000/yr.
Evaluation of Previous Pipeline Abandonment programs	$100,000 plus $25,000/yr.
Collapse of Soil Under Various Conditions	$300,000
Validation of Culvert Failure Model for Abandoned Pipelines	$40,000
Validation of Structural Integrity Models	$30,000

1 INTRODUCTION

On July 6, 2010, the National Energy Board (NEB) issued a Request for Proposal (RFP) for the completion and submission of a pipeline abandonment study. The RFP indicated that a multi-stakeholder Pipeline Abandonment Physical Issues Committee wished to address specific gaps in knowledge or other issues related to the physical aspects of onshore pipeline abandonment related to both landowner and industry interests. This would include but not be limited to studies or research related to:

- Ground subsidence and frost heave;
- Soil and groundwater contamination;
- Pipe cleanliness;
- Road, railway and utility crossings;
- Water crossings;
- Erosion; and
- Creation of conduits.

The objectives of this project were to conduct a literature review regarding the current understanding worldwide with respect to the physical/technical issues associated with onshore pipeline abandonment and use the results of the literature review to critically analyze and identify gaps in current knowledge, and make recommendations as to potential future research projects that could help to fill those gaps.

Det Norske Veritas (DNV) partnered with TERA ENVIRONMENTAL CONSULTANTS and BGC ENGINEERING INC. to submit a proposal in response to the RFP and on 4, August 2010, the project team was awarded the contract.

2 APPROACH

To conduct the literature review, subject matter experts (SMEs) in Engineering, Environmental, and Geotechnical issues identified the keywords that were used to conduct the literature searches. Additional keywords were also provided by members of the NEB's Pipeline Abandonment Physical Issues Subcommittee. Based on the keyword list, titles of papers and related abstracts were identified through the literature searches. The literature searches were performed using two search engines; Engineering Village and Science Direct. Engineering Village searches all areas of engineering and includes the article abstract databases COMPENDEX and NTIS. Science Direct is a product of Elsevier B. V. and contains over 10 million articles and book chapters in the fields of science, technology, and medicine. Subject matter experts reviewed the results of the literature searches and identified specific references they considered to be potentially relevant to the study. The identified papers were then obtained and the SMEs reviewed the papers applicable to their subject area.

DNV provided overall project management as well as the SMEs to address the Engineering issues identified for the project. TERA provided SMEs to address the Environmental issues. BGC provided SMEs to address the Geotechnical issues. Land Management issues were addressed by all SMEs as applicable.

This report outlines the results of the literature review, identifies knowledge gaps, and provides scoping for further studies and research on physical abandonment issues related to onshore pipelines in Canada.

3 BACKGROUND

3.1 Past Studies

Pipeline abandonment has been a topic of discussion in the Canadian oil and gas industry for over 25 years. This summary is taken from the NEB's Land Matters Consultation Initiative, Stream 4 – Pipeline Abandonment - Physical Issues, and is based on three previous studies undertaken in 1985, 1996, and 1997.

In 1985, NEB staff reviewed technical, environmental, and financial issues associated with pipeline abandonment (the 1985 NEB Staff Paper). In 1996, the Pipeline Abandonment Steering Committee, a collaboration of the NEB, Alberta Energy Utilities Board (EUB), Canadian Energy Pipeline Association (CEPA) and Canadian Association of Petroleum Producers (CAPP), developed a discussion paper (the 1996 Discussion Paper) that examined the physical and technical issues associated with abandonment. In particular, this latter paper provides a template for abandonment planning and implementation. In 1997, the same collaboration examined legal issues relating to abandonment (the 1997 Legal Paper).

In addition, as part of the process of developing the 1996 Discussion Paper, the Pipeline Abandonment Steering Committee commissioned four reviews of specific technical issues. The reviews examine trace pipeline contaminants, corrosion, pipeline related subsidence and environmental issues respectively and are also referenced herein.

Physical and technical issues of retirement and reclamation can be organized into six principal sections:
1. Retirement options;
2. Engineering issues;
3. Land use considerations;
4. Environmental issues;
5. Post-abandonment; and
6. Principles for pipeline abandonment.

1. Retirement Options

Three approaches to pipeline retirement are possible:

a) Removal
b) Abandonment in-place
c) Reuse of facilities

Pipeline Retirement Option Matrix - a key factor influencing the choice of retirement options is present and future land use. This is reflected in the Table below, which provides a matrix adapted from the 1985 paper.

Retirement Option Matrix[1] (from PADP 1996)

Land Use		Pipeline Diameter			
		60.3 to 203 mm (2" – 8")	**273 to 550 mm (10" to14")**	**406 to 550 mm (16" – 20")**	**610 to 1219 mm (24" to 48")**
Agricultural	Crop	A	R	R	R
	Crop (with depth of cover considerations)	R	R	R	R
	Pasture (inc. native prairie & rangeland)	A	R	R	R
Non-Agricultural	Rock	A	A	A	A^+
	Till	A	A	A	A^+
	Cohesive Soil	A	A	A	A^+
	Granular Soil	A	A	A	A^+
	Wetlands	A^+	A^+	A^+	A^+
Urban	Suburban	A	A	A^+	A^+
	Park	A	A	A^+	A^+
	Urban	A	A^+	S	S
	Industrial	A	A^+	S	S
Crossings	River	A	A^+	A^+	A^+
	River Approaches	A	S	S	S
	Rail	A	A^+	A^+	A^+
	Road	A	A^+	A^+	A^+
	Secondary Road	A	A	A^+	A^+
	Pipeline	A	S	S	S
	Sewer	A	A	A^+	A^+
	Cable	A	A	A^+	A^+

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Option	Description
A	Abandon in-place recommended
A^+	Abandon in-place with special treatment to prevent ground subsidence.
R	Remove pipe
S	Site-specific evaluation recommended

Note: CEPA and NEB have developed updated Retirement Option Matrices which are included Appendix B of this report.

2. Engineering Issues

a) Corrosion

The 1996 Discussion Paper and an associated corrosion study examined the causes and timing of corrosion associated with abandoned pipelines. The Corrosion Study suggested that, while coating defects affect less than one percent of the length of most pipelines, corrosion will eventually result in random perforations throughout the length of the pipeline.

b) Pipeline collapse

As the pipe becomes pitted with corrosion, it will eventually collapse. Collapse may have few consequences for small-diameter pipes (6”/168 mm or less). However, collapse of large diameter pipes can lead to subsidence, which in environmentally or geo-technically sensitive areas would require back-filling and restoration. Given the non-uniform nature of the corrosion process, it is unlikely that significant lengths of pipeline will collapse at any one time.

The 1985 NEB Staff Paper suggests options for managing concerns for large diameter pipeline collapse that includes developing a tool to collapse a line prior to abandonment and/or filling a line, or at least critical sections of it (e.g. stream crossings, under railways), with a liquid that can solidify (e.g. cement).

3. Land Use Considerations

As the previously referred to reviews have concluded, land use is the most important factor to consider when determining whether to remove a pipeline section or abandon it in place. Of particular concern are sensitive areas, including:

- Native prairie;
- Parks and ecological reserves;
- Unstable or highly erodible slopes;
- Water crossings
- Areas susceptible to wind erosion;
- Irrigated land; and,
- Road, railway, and other utility crossings.

The pipeline industry must manage these issues and land use in general within three types of land rights: easement; fee simple; and leasehold lands.

4. Environmental Issues

Both the 1985 NEB Staff Paper and the 1996 Discussion Paper examine the environmental issues associated with pipeline retirement. The 1996 report is based, in part, on a review of environmental issues for pipeline retirement commissioned by the Pipeline Abandonment Steering Committee.

a) Soil and groundwater contamination
The Committee also commissioned a study to examine the types and quantities of contaminants that could be released from pipelines abandoned in-place.
Potential sources of contamination that were identified include:
- Substances in the hydrocarbon stream;
- Pipe treatment chemicals;
- Pipeline coatings and their degradation products;
- Historical leaks and spills of product not cleaned up to current standards;
- Pump and compressor lubricants, some of which could contain PCBs from past use.

Contamination risks are arguably greatest for pipelines abandoned in-place. The pipe will eventually be perforated by corrosion, allowing contaminants to migrate into the surrounding environment. Potential also exists for corroded pipe to act as a water conduit, transporting any contaminants present to other points along the pipeline. The cleanliness of the pipe is an important factor relating to potential soil and/or groundwater contamination from abandoned pipe. The 1996 Discussion Paper indicates that the question of "how clean is clean" remains to be answered.

b) Soil resources
Where pipe is to be removed, the erosion issues will be similar to those associated with installation.
Abandonment in-place can lead to erosion in two ways. Corrosion perforated pipe can conduct water along the right-of-way to exit the pipeline in new locations. Later, as the pipeline collapses, resultant soil subsidence can create water conduits able to intercept and channel drainage along the right-of-way, potentially, at much greater velocities than natural drainage patterns would allow.
To examine ground subsidence risks for abandoned pipelines the Pipeline Abandonment Steering Committee commissioned both a geotechnical study and a survey of pipeline companies. Neither the industry survey nor follow-up discussions identified any instances of observed subsidence. However, the Committee recommended that a field observation program be put into place that would allow tolerance criteria to be developed. This remains to be done.

c) Creation of water conduits
The potential for pipelines to create water conduits as a result of abandonment creates risks of unnatural drainage and unwanted transport of materials that can include eroded soils and contaminants. Some potential exists for water movement in un-compacted, back-filled trench material that may remain after the pipe has been removed. However, the greatest concern relates to pipelines abandoned in place.
The 1996 Discussion Paper identifies measures such as pipeline plugs and trench breakers for managing the risk of undue water mobility. The material suggests that this issue is understood and manageable.

d) Pipeline water crossings
Even after pipeline retirement, water crossings remain a key environmentally sensitive location on pipeline rights-of-way. While the water quality, fisheries and geomorphology issues associated with pipeline water crossings are well documented, most work is primarily from the point of view of pipeline installation.
Pipes abandoned in-place at water-crossings could contaminate surrounding water as corroded pipe fails and/or the pipe could be exposed. Pipe can be exposed in streams by stream bank erosion and migration, scouring of the stream channel and by other similar erosion mechanisms. Pipes may be exposed in still waters and wetlands because of pipe buoyancy if control mechanisms (e.g. concrete saddle weights) fail.

5. Post-Retirement
The 1996 Discussion Paper provides a concise template for retirement planning together with information on addressing the principal technical and environmental issues. A major issue identified was the responsibility for monitoring and maintenance. The 1997 Legal Paper examines legal issues associated with retirement and focuses much of its attention on the issue of ongoing responsibility for the retired pipeline right-of-way. The Legal Working Group concluded that "*in the absence of an express provision to impose conditions which would continue after the abandonment order comes into effect, [*the NEB concluded*] that it has no authority to attach conditions subsequent to an abandonment order*". In response, to the extent that it has had to address the retirement, the Board has adopted an approach that requires regulated pipelines to satisfy conditions precedent before a retirement can take effect.

6. Summary of Outstanding Issues
a) How clean is clean?
The 1996 Discussion Paper identifies the lack of allowable threshold criteria for contaminants as a gap.

b) Corrosion and its effects
A better understanding of the rate of corrosion in various soil types and the effects of corrosion on surrounding soil is required. Also, the actual collapse mechanism of a retired pipeline failing due to corrosion is not known hence its effect on subsidence remains unknown.

c) Practical experience with pipeline related soil subsidence.
While the Pipeline Abandonment Committee undertook an industry survey in 1996, looking for examples of pipeline related soil subsidence, the responses provided little information. In response, the Paper recommended that a field investigation program be undertaken that could lead to the development of tolerance criteria for pipeline related soil subsidence.

d) Retirement of facilities at water crossings
Knowledge surrounding the impact of corrosion on water surrounding an abandoned-in place pipeline as well as the impacts of pipe exposure in a water crossing needs to be assessed.

e) The exact nature of the Board's jurisdiction and approach to retirement going forward. Responsibility for enforcing responses to problems that may occur on retired pipeline rights-of-way that was previously federally regulated appears uncertain. There may be steps that can be taken to clarify this gap.

4 RESULTS OF LITERATURE REVIEW

4.1 Codes and Standards

DNV has reviewed the code recommendations regarding pipeline abandonment, or "permanent de-commissioning" as it is known in the UK, from a variety of countries, including Canada and the United States, the United Kingdom, Australia and South America (Argentina and Chile, although no guidance is given in either of these codes). Full details, including quotations taken directly from codes, where applicable, are presented in Appendix A.

Essentially, no significant differences have been found between the various standards; all give general guidance on what pipeline operators must consider without going into detail. The majority of the standards reviewed stipulate that "the decision to abandon a section of piping, in place or through removal, shall be made on the basis of an assessment that includes consideration of current and future land use and the potential for safety hazards and environmental damage to be created by ground subsidence, soil contamination, groundwater contamination, erosion, and the creation of water conduits" or words to similar effect (the quotation is taken from CSA Z662-07).

CSA Z662-07 states, similar to most of the codes reviewed, that piping that is abandoned in place shall be:

(a) Emptied of service fluids;

(b) Purged or appropriately cleaned or both;

(c) Physically separated from any in-service piping; and

(d) Capped, plugged, or otherwise effectively sealed.

and that records shall be maintained of all piping that is abandoned in place. Such records shall include locations and lengths for each pipe diameter and where practical, burial depth.

Both ANSI/ASME B31.4 and B31.8 have very similar clauses.

With respect to UK standards, DNV has reviewed the national standard for gas pipelines, as well as the relevant ISO, European and national pipeline "standard" (the "standard" is in fact a British Standard "Published Document" as ISO and (on a hierarchal basis) European standards must be used in preference to British Standards). However, the authors have learnt that ISO and European standards are often regarded as overly generic, and companies will therefore invoke the requirements of all three "standards". Appendix A demonstrates that the requirements of both the ISO and BS EN standards are very sparse, but more details are given in PD 8010-2004; again, the guidance is similar to the North American standards, although pipeline cover is stipulated, together with the need to consider using filler materials in certain abandoned sections. The standard for gas pipelines, IGEM TD/1/Version 5, within the UK gives more detail, including:

- Considerations of alternative uses for the (to be abandoned pipeline),
- Filling with inert gas if necessary,
- Land use and legal/landowner considerations,
- Future maintenance of the pipeline, e.g. to prevent possible collapse,
- The need for line markers, and
- The removal of short, above ground sections.

Finally, the Australian national standard AS 2885.3 has been reviewed, which is similar in outline to TD/1, although it states that line markers are not required after abandonment. It is the only standard reviewed which states that cathodic protection systems may need to be continued and the system maintained after pipeline abandonment. The standard also states that, before abandoning the pipeline, landowner releases for the completed abandonment must be obtained and the pipeline operator should relinquish the easement where no future or continuing use of the easement is proposed.

4.2 Environmental & Land Use

This Section presents a summary of the key documents forming the foundation of this report and a synopsis of all relevant documents discovered by the literature search completed as described in Section 2.

This section is structured to address the nine specific environmental components identified below:

- Detection of Residual Contamination
- Environmental Standards
- Risk Assessment
- Conduit Effect
- Decomposition of Pipe Material
- Cleaning Methods and Disposal of Fluids
- Disposal of Pipe Material
- Abandonment in Sensitive Ecological Areas
- Abandonment under Water Bodies

These topics were identified by the committee to address contamination remediation, reclamation, and protection of sensitive ecological areas. From an understanding of the past studies summarized in Section 3 and by careful review by subject matter experts (SMEs) of the subsequent literature, it is believed that the list of topics is comprehensive.

For each of the nine topics, the information gleaned by the SMEs is presented in the following sub-headings:

a) *Background Information* - The key background documents (Section 3) are well known to the National Energy Board (NEB) Pipeline Abandonment Physical Issues Committee so this sub-section is not intended to summarize those reports but rather present the key observations relevant to each of the 9 specific environmental components.

b) *Recent Findings* - This sub-section builds from the key background documents drawing on the information found in the literature review.

The purpose of this report is to identify the current state of knowledge with respect to pipeline abandonment and recommend to the NEB Pipeline Abandonment Physical Issues Committee, studies, research or tasks intended to fill knowledge gaps. The environmental recommendations are presented in Section 5.1. These have been developed by the SMEs from an understanding of the key background documents, this literature review and practical knowledge of current practice in the pipeline industry. In most instances, the authors have not attempted to suggest a priority for these tasks. We feel the NEB committee is better positioned to decide priorities.

The literature search discovered 83 documents that appeared relevant to onshore pipeline abandonment. Specifically, 36 appeared to have environmental themes. All of these are listed in Section 6 and any that offered discussion or recommendations that the environmental SMEs deemed meaningful are mentioned in this section.

4.2.1 Detection of Residual Contamination

Background Information

A number of different contaminants were identified as having the potential to be present in pipelines; however, the concern is the quantity of residual contaminants left in the interior of the pipeline at abandonment. Methods for analyzing levels of *known* contaminants in soil and water as a result of spills are well established. However, developing a methodology for accurately measuring the presence and quantity of contaminants remaining in a section of abandoned pipeline remain unclear.

A review of literature indicates that it was possible for polychlorinated byphenyls (PCBs) to have entered pipelines and peripheral facilities through the use of PCBs in lubricants at some point in the history of a pipeline system. Despite the cessation of use of PCBs for over 20 years, they can persist in the environment due to their chemical stability. Measurements of PCB concentrations along gas pipelines were not lending themselves to accurate conclusions, in part because there is no systematic protocol for ensuring comparable results. Consequently, proper management of

PCBs is difficult because estimations with respect to PCB concentrations along remaining pipelines cannot be produced. Estimating PCB concentrations is also made difficult due to the lack of information on PCB dynamics within pipeline systems.

Another potentially harmful substance present in both oil and gas pipelines is naturally occurring radioactive material (NORM). During the production process, NORM flows with the oil, gas, and water mixture and can accumulate in scale, sludge and scrapings within a pipeline. It can also form a thin film on the interior surfaces of gas processing equipment and vessels. The level of NORM accumulation can vary substantially from one facility to another depending on the geological formation, operational, and other factors.

As of 1996, little research had been done in terms of the development of guidelines for the testing and handling of NORM. In general, contaminant testing would be more efficient if the types and volumes relative to different pipeline products and locations within the distribution system were better understood.

The clean up of any spills, leaks, or contaminated sites must be conducted in accordance with prevailing regulatory requirements. Any pipeline failure resulting in a release of liquid having a volume greater than 1.5 m^3 must be reported by the pipeline operator pursuant to the NEB *Onshore Pipeline Regulations 1999* (OPR). Spills, as a result of pipeline failures and facility operation activities, are also reported to provincial regulators such as the Alberta Energy Resources and Conservation Board, Saskatchewan Energy and Resources and the British Columbia Oil and Gas Commission. Guidelines and procedures for managing spills and contaminated sites have also been established by federal and provincial regulators. However, very little information can be gathered regarding the occurrence of spills following the abandonment of pipelines as very few examples of abandonment projects exist in Canada (CEPA 2007).

Recent Findings

While conducting pipeline removal, Yukon Pipelines Limited collected soil samples every 100m along the pipeline for visual observations and organic vapour monitoring (Roblin 2006).

An example of a monitoring program set in place as part of a pipeline abandonment operation using *in-situ* biological degradation of certain contaminants is provided from the Schoonebeek Oilfield, Netherlands (Kant *et al.* 2010). It was found that, depending on the progress of the degradation process, the monitoring scheme was reconsidered and adjusted at regular intervals, and if disappointing remediation results occurred, a selected remediation alternative would be considered.

In 2008, the International Association of Oil and Gas Producers (IAOGP) released NORM guidelines specific to the oil and gas industry. Mentioned in the report is that NORMs can be either directly measured or assessed in a laboratory. In Canada, guidelines are present that cover NORM detection and handling procedures, as well as limits and exemption levels for the various radionuclides that may occur (Health Canada 2000). In the absence of national regulations, current international practice will also provide such guidelines (International Atomic Energy Association [IAEA] 2010).

In a 1991 study entitled *Gas Research Institute* (GRI) *Pipeline Research Program* (Linz *et al.* 1991), the authors state that sampling and analytical procedures commonly used for PCBs by electric utilities and other industries do not apply well to gas pipelines. Further, the authors state that negotiations were ongoing at the time between the gas industry and the United States Environmental Protection Agency (EPA) regarding both development of a statistical model to use for system characterization, and a methodology or systematic protocol to quantify residual pipe contamination. At the time, the GRI was also conducting a method development task (to establish procedural methodology) using an assortment of contaminant types. In addition, GRI was studying the partitioning of PCB within different soil and water types. The study mentions that the EPA is moving toward a liquid sample based "moving average" approach as opposed to the expensive and time consuming 1% incidence approach for statistical analysis of PCB concentrations in pipelines.

In a study entitled *The TSCA PCB Regulations and Their Effect on Pipeline Removal and Abandonment Programs* (La Shier 1989), the author mentions the need for further development of statistical analysis techniques for measuring PCB concentrations in pipelines. A sound statistical model is needed because PCB concentrations vary considerably throughout the pipeline system.

A study was conducted regarding the statistical analysis of PCB data from natural gas pipelines, which aimed to further establish both a sound sample method and an understanding of statistical distribution of PCBs along pipelines (Bishop *et al.* 1990). However, due to the limited size and scope of the study, the authors felt it was "imprudent" to draw definitive conclusions regarding the implications of their results.

4.2.2. Environmental Standards

Background Information

The National Contaminated Sites Remediation Program (NCSRP) was administered through bilateral agreements between the federal government and participating provincial/territorial environment departments with the aim of developing a consistent, scientifically defensible and cost-effective assessment and remediation plan for contaminated sites (NCSRP 1993, Canadian Council of Ministers of the Environment (CCME) 2006). Canada-wide standards for soil quality guidelines have since been developed and are well established by the CCME at the closing stages of the NCSRP in 1995 (CCME 1999a). Generic guidelines have been derived to protect human health and key ecological receptors that sustain normal activities on four land use categories: agricultural, residential/parkland, commercial, and industrial. Generic land use scenarios are envisioned for each category based on how the land is used and on how sensitive and dependent the activity is on the land. Sensitivity to contamination increases among ecological or human health components most dependent on land use activities (*i.e., agricultural and residential/parkland).*

Recent Findings

CCME's environmental soil quality guidelines were derived through the determination of the threshold level of effects for maintaining important ecological functions associated with specific land uses. Direct exposure to soil is the primary derivation procedure for environmental quality guidelines regarding residential/parkland, commercial, and industrial land uses. The Canadian soil quality guidelines have been derived specifically for protection of the ecological receptors in the environment and/or for the protection of human health associated with the identified land uses. Human health soil quality guidelines provide concentrations of contaminants in soil at or below which no appreciable human health risk is expected. The protection of human health takes into account the daily background exposure from air, water, soil, food, and consumer products. Indirect exposure pathways resulting from contaminated soils were also considered during the derivation of human health guidelines. In the case of agricultural land use, another derivation procedure is used based on soil and food ingestion (CCME 2006). CCME has established its Policy for the Management of Toxic Substances (1998) for the purpose of putting in place a results-based, accelerated action plan that all jurisdictions can utilize, and provides opportunity for public and stakeholder participation.

The CCME has several specific documents that aid in appropriate management and remediation of contaminated sites associated with the oil and gas industry.

The Canada-Wide Standards for Petroleum Hydrocarbons in Soil (PHC CWS) uses a three-tiered approach as a remedial standard for contaminated soil and subsoil occurring in four land use categories. The first tier is the direct adoption of Canadian soil quality guidelines (numerical limits [CCME 2007]) while the second tier allows limited modification of Canadian soil quality guidelines by setting site-specific objectives. The third tier uses risk assessment procedures to establish remediation objectives at contaminated sites on a site-specific basis (CCME 2008).

The Canadian Soil Quality Guidelines for carcinogenic and other polycyclic aromatic hydrocarbons (PAHs) contain recent scientific information on the chemical and physical properties of potentially carcinogenic and other commonly analyzed un-substituted PAHs, a brief review of sources and emissions in Canada, the expected environmental fate, and the toxicological significance of these PAHs to soil microbial processes, plants, animals and humans (CCME 2010).

The Canadian Soil Quality Guidelines for polychlorinated biphenyls (PCBs) contain guidelines for the protection of environmental health, but also recognizes a need for remediation guidelines as interim management objectives for persistent bio-accumulative substances in soils (CCME 1999b).

The Canadian Soil Quality Guidelines for benzene, toluene, ethylbenzene and xylene (BTEX) contain guidelines for the protection of environmental health (CCME 2004).

CCME has adopted a three-tired approach for dealing with contaminated site assessment and remediation. The first tier is the direct adoption of Canadian soil quality guidelines. However, the fact that some sites might present particular conditions (*e.g.*, high natural background concentrations, complex mixtures of contaminants, or unusual exposure scenarios) must also be considered. For these sites, the second tier allows limited modification of Canadian soil quality guidelines by setting site specific objectives. Finally, the third tier uses risk assessment procedures to establish remediation objectives at contaminated sites on a site-specific basis.

In July 2010, the NEB introduced the Draft Remediation Process Guide. This Guide describes the way a company can demonstrate that a contaminated site associated with an NEB regulated facility has met remediation criteria. This Guide applies to NEB-regulated facilities under the *National Energy Board Act* (NEB Act) and the *Canada Oil and Gas Operations Act* (COGOA). At a minimum this Guide applies to:

- Remediation of residual contamination in soil and groundwater to an appropriate standard;
- Remediation of all spill sites whether the spill is reportable or not;
- Off-site contamination remediation; and
- Historic contamination events.

The NEB accepts remediation criteria established by the province or territory where the remediation site is located as a baseline but requires the use of CCME standards if the criteria are more stringent. Remediation criteria must be selected based on the type of soil and land use. Typical land use categories are industrial, commercial, residential, parkland, and agricultural. Justification for the use of particular criteria must be provided.

Provincial governments have adopted the CCME standards with some provinces using the CCME guidelines as a platform from which further directives and guidelines have been established. For example, Alberta includes natural areas as an additional land use category (AENV 2009).

In a case study of the 1996 abandonment of a Yukon Pipelines Limited pipeline stretching from Whitehorse to Skagway, contaminated soils were compared with CCME criteria, and groundwater samples were compared with both the Yukon Contaminated Site Regulation and CCME drinking water criteria.

The Canadian Guidelines for the Management of NORM have been developed by the NORM Working Group, a working group of the Federal Provincial Territorial Radiation Protection Committee (FPTRPC), representing the interests of provincial and territorial regulators and includes affected industries in the petroleum production, fertilizer manufacturing and metal recycling industry sectors. With the support and encouragement of Health Canada and the Canadian Nuclear Safety Commission, the Canadian Guidelines set out principles and procedures for the detection, classification, handling, and material management of NORM in Canada, and also include guidance for compliance with federal transportation regulations. These

Guidelines provide the framework for the development of more detailed NORM management practices and guidelines by regulatory authorities, affected industries and specific workplaces.

4.2.3 Risk Assessment

Background Information

Conducting risk assessments for abandoned pipelines is a key procedure that should be implemented to ensure protection of ecological receptors and/or for the protection of human health. To start, abandoning a pipeline in-place must be weighed against the environmental impact of removal, and should be site specific (PADP 1996).

Components considered in a site-specific risk assessment are largely related to environmental variables that may jeopardize pipeline integrity, causing stress and/or corrosion related cracks and eventual disintegration, facilitating contamination release, water displacement, point source erosion and subsidence. Although assessment of risks associated with pipeline abandonment includes external environmental variables affecting pipeline integrity, it is the potential damage that toxic substances, if released, may have on particular receptors.

To begin a risk assessment, a field study of residual contaminants in pipelines prepared for abandonment should be conducted. The study should include the determination of the nature and quantity of residual contaminants for the range of operating conditions and products typically found in Alberta (Thorne *et al.* 1996). A risk management plan should then be developed and include factors such as: type of contaminants, differences in product, pipeline construction, operating conditions and environmental sensitivity, and lack of detailed information (Thorne *et al.* 1996).

As mentioned in Section 4.2.2, Canada-wide standards for soil quality guidelines have been developed and are well established by the CCME. The soil quality guidelines provide concentrations of contaminants in soil at or below which no appreciable human health risk is expected. The protection of human health takes into account the daily background exposure from air, water, soil, food, and consumer products. Indirect exposure pathways resulting from contaminated soils, such as contaminated groundwater, contaminated meat, milk, and produce, infiltration into indoor air, and wind erosion resulting in deposition on neighbouring property were also considered during the derivation of human health guidelines.

Recent Findings

The Canadian Energy Pipeline Association (CEPA) recognizes that a risk-based, comprehensive site specific assessment is essential in determining appropriate abandonment procedures for specific pipelines (2007). However, CEPA also states that a risk-based decision process to support the required site-specific assessments has not yet been developed. In addition, the lack of environmental baseline data (*e.g.* interactions and pathways of specific contaminants released in different soil and groundwater systems) makes restoration requirements difficult to assess

(Sookdeo 2002). Furthermore, ongoing controversies pertaining to the definition of pipeline cleanliness specifications must be resolved in order to develop such a decision process (CEPA 2007). Although it is evident there are many issues to be resolved in order to develop a robust and comprehensive risk assessment approach, key considerations that should be included in any risk assessment are listed by the authors of *Decision Procedures for Pipeline Rehab* (Hodgdon *et al.* 1991). They state that risk analysis is a flexible technique that can include:

- Management assessment of risk whereby management has sufficient data and information to reach the decision that risks exist and action is necessary;
- Comparative risk assessment whereby the risks in several segments of a pipeline system are developed on a comparative basis in order to assign priorities to the segments for budget and scheduling purposes; and
- A risk analysis that determines the probabilities and seriousness of risk at a specific site.

In addition to the above recommendations, much insight can be collected from recent experiences and investigations into the matter:

The authors of *Oilfield Abandonment and Soil Restoration in the Netherlands, Experience for the Future* (Kant et al. 2010) discuss risk assessment and subsequent remediation techniques used on a large oilfield abandonment project in the Netherlands. In the Netherlands, soil-risks can be modelled in a semi-quantitative manner as a result of the establishment of Soil Protection Guidelines (based on long term collection of data) that ensure permit conditions are uniform. This allowed remediation measures to be attuned to the actual risks of residual contamination. For example, if conditions permitted, slightly contaminated soil was left or put back. This "fit for use approach, or function-oriented remediation approach, whereby pollutant concentrations in soil and groundwater were remediated to levels associated with land use, proved practical and cost effective, allowing resources to focus on areas of greatest over-all risk without compromising risks of lesser significance or immediacy. In general, however, the preferred approach (though more costly) would be multifunctional remediation, whereby all contaminated sites are remediated so that no risks exists no matter what the land use.

The authors of *Use of Risk-Based Business Approach for Characterization of Environmental Remediation Liabilities in Upstream Oil and Gas Production Facilities* (Connor et al. 2008) discuss a Risk-Based Corrective Action (RBCA) risk classification system for characterization of site conditions. This system, discussed in detail in the paper, is designed to characterize site conditions and risk distribution in terms of the magnitude and immediacy of the risks posed, thereby facilitating development of a corrective action program schedule and budget designed to address imminent concerns in the near-term and non-imminent concerns over the long-term. This RBCA risk classification system could be adopted for pipeline abandonment, used to distinguish between necessary immediate actions and actions that can be postponed until later depending on the type of monitoring information gathered or other non-immediate characteristics of the risk (e.g. location, subsidence etc).

Government Directives and Guidelines

The NEB Draft Remediation Process Guide recognizes that not all contaminated sites accommodate typical remediation approaches; for example, in the following situations:

- National criteria for a contaminant does not exist;
- Remediation to guideline-based criteria is not feasible for the targeted land use;
- Guideline-based objectives do not seem appropriate given the site specific conditions, (i.e. recovery of the contaminant is too deep or otherwise unfeasible to access) so a risk assessment is necessary to establish site specific objectives;
- Receptors of concern have been identified; or there is significant public concern, as determined by the lead agency.

In these situations, the Guide recommends a risk management approach be followed. This involves the selection and implementation of a risk control strategy based on site specific objectives. Monitoring and evaluation of the strategy's effectiveness is required. The CCME approach is recommended. Risk management may include direct remedial actions or other strategies that reduce the probability, intensity, frequency or duration of exposure to contamination through soil, water or air/vapour pathways. The latter may include controls such as zoning designations, land use restrictions or orders. The decision to select a particular risk-based strategy will be informed by risk assessment information.

Alberta Environment incorporates site-specific risk assessment (SSRA) guidance and remedial objectives in its *Tier 2 Soil and Groundwater Remediation Guidelines* (2009). Mentioned in the Tier 2 document is that in all instances, site specific remediation objectives will require use of procedures, protocols, and monitoring that are acceptable to Alberta Environment. Where there are no clear guidance documents that have been accepted by Alberta Environment, discussion with Alberta Environment will be necessary prior to acceptance of final Tier 2 SSRA remediation objectives. Site-specific risk assessment may be triggered by a number of conditions, including situations in which Tier 1 and/or Tier 2 pathway and receptor exclusion and guideline adjustment approaches are either precluded by technical or policy factors or where site specific risk assessment is clearly demonstrated to offer the same level of protection as the Tier 1 objectives. The guideline continues, addressing the basis and considerations for SSRAs, implementation of site-specific remediation objectives and identification of conditions/restrictions associated with SSRA. The guidelines also cover the roles of, and approaches to, exposure control, circumstances precluding exposure control and requirements for exposure control.

In 2004, Health Canada released a document entitled *Federal Contaminated Site Risk Assessment in Canada*. This document was released to standardize guidance for consistent assessments on federal contaminated sites. These cover hydrocarbon related contamination rather extensively, and could be considered in the oil and gas abandonment and remediation process. These preliminary quantitative risk assessment (PQRA) guidelines are different from more complex site-specific risk assessments (SSRA). Nevertheless, the two assessments are not independent and can in fact work together to produce a more accurate, precise, realistic, reliable, and defensible quantification of risks (Health Canada 2004). Health Canada is currently working on a guidance manual for conducting SSRAs which will be published when the work is complete.

4.2.4 Conduit Effect

Background Information

For in-place abandonment of pipelines, the conduit effect refers to the migration and discharge of water through the pipeline resulting from perforations caused by excessive corrosion or outside forces. Modern pipeline coatings provide substantial protection; however, an estimated 1% of external pipeline surfaces are not coated (Webster 1995). Furthermore, coatings may be improperly installed, defective or damaged from either construction or natural activities.

Significant environmental impacts have the potential to occur resulting from the conduit effect. The level of cleanliness within the pipe will determine the magnitude of the potential impacts resulting from point-source leaks along the damaged pipeline. It has been suggested that water displacement and flow as a result of perforations could lead to drainage of wetlands, or flooding of low lands. In addition, if abandoned pipelines are not completely cleaned, it has also been suggested that water within the pipeline may accumulate excessive contaminant loads, depositing them near sensitive areas (*e.g. wetlands, watercourses etc)* or in surrounding soils and groundwater (PADP 1996). In addition it has been suggested that any water discharge has the potential to cause subsurface erosion resulting in ground instability and surface subsidence.

In order to inhibit the transfer of water through a pipeline, it has been suggested that plugs could be installed at an appropriate spacing and along certain terrain features to ensure that changes in surface and ground water conditions will not result in water flow (H.R. Heffler Consulting Ltd. *et al.* 1995, PADP 1996,). When identifying plug locations, one should consider pipeline access and the resulting effects of the ground disturbance (PADP 1996). Furthermore, water discharge points should be created along slopes to reduce excessive erosion and flooding of low areas where the pipeline flattens out (PADP 1996).

The flow and displacement of water may also occur through uncompacted materials along a trench where pipeline was removed (Roblin 2006). Sediment packing, as well as installation of trench breakers and subdrains are appropriate mitigation measures (PADP 1996, Thorne *et al.* 1996, Roblin 2006).

Recent Findings

When discussing the environmental impacts and mitigation measures associated with the conduit effect, CEPA, in their 2007 report, stated that no new information was collected. Putting negative impacts aside, positive research has been done exploring pipelines abandoned in-place as conduits for alternative applications.

In a publication entitled: *Use of Abandoned Pipeline to Transport Sediment to Marshes* (Coates 1994), the author argues abandoned pipelines have the potential to be used for nourishment of existing marshes by transport of freshwater with nutrients and finer sediments. The author also considers the utilization of pipelines to transport sediment to restore marshes as technically feasible.

In a publication entitled: *Multiproduct Pipe Transport Conversion of Abandoned Single Product Pipelines* (Davis et al. 2005), the author presents a methodology for creating and controlling multiple pipelines that are installed within a larger outside diameter (O.D.) line. One benefit of this is reduced construction related environmental damages.

In a publication entitled: *Contractors' Concept of Optical Fibre in Sewers of Abandoned Pipelines* (Welch 2004) the application of pipelines as conduits for optical fibre cables is explored. Benefits of this application include fewer construction related nuisances to the public, reduced impact to the environment and safer, more compact utility corridors.

4.2.5 Decomposition of Pipe material

Background Information

Pipelines bodies consist of 97 to 99% iron by weight, followed by 0.5 to 2.0% manganese, 0.5 to 1.0% copper, nickel, molybdenum, chromium and carbon. Trace elements (less than 0.1%) are sulphur, phosphorus, tin, lead, bismuth and arsenic. The types of material associated with pipelines coatings are coal tar, enamel, polyethylene tape, asbestos, asphalt, high density polyethylene and fusion bonded epoxy. Presently, polyethylene and fusion bonded epoxy are the most widely used coatings. Pipeline coatings used in the 1950's and 1960's included blown bitumen or coal-tar pitch covered by glass-fibre cloth, bituminized paper, hessian, or asbestos felt. In Alberta, asbestos felt wrap was used into the early 1970's (Thorne *et al.* 1996).

Metals released from the pipeline body from corrosion corrode to a state of lower environmental mobility, and are generally not considered a potential environmental threat. Carcinogenic PAHs present in coal tar enamel was one of the leading causes of an industry switch to polyethylene. Polyethylene is considered safe to work with, and does not produce toxic leachates (Thorne *et al.* 1996).

Ground subsidence resulting from excessive deterioration and subsequent pipeline collapse is little understood, as of 1996 no data on the phenomenon was currently available. There are many uncertainties in predicting subsidence. For example, temporal relationships of pipeline degradation and how the magnitude and impact such degradation will influence subsidence is poorly understood. Nevertheless, it is improbable that a sudden collapse will lead to a depression of the soil cover as deep as the pipe diameter over an extended length of the pipeline (Geo-Engineering Ltd. 1996). Any subsidence is likely to be localized and intermittent.

Recent Findings

There is limited new information regarding the impacts of contaminant release resulting from pipeline decomposition. One study on subsea in-place abandonment found that, since PAH is not very water soluble; it will become a major environmental hazard only when organisms feed on particulate material (Scandpower Risk Management Inc. 2004). This could be an environmental concern in wetter areas for onshore pipeline abandonment.

In its 2007 report, CEPA concluded that pipelines of diameters greater than 12 inches will still be within tolerable ranges of subsidence, and that pipeline structural integrity would be retained for decades, if not centuries. CEPA still recognizes, however, that considerable work is needed to validate subsidence risks resulting from corrosion.

4.2.6 Cleaning methods and disposal of cleaning fluids

Background Information

The most critical determinant for ensuring pipe cleanliness is effective pigging (PADP 1996, Thorne *et al.* 1996). Preferably, in-place abandoned pipelines should be cleaned free of solids or any waxy build up (PADP 1996). However, studies have shown that significant quantities of contaminants may be left in abandoned pipelines as a result of poor pigging operations. A number of factors influence the efficacy of pigging operations such as pipeline configuration (*e.g.* bends and doglegs), pig type and proper pig use. Even with effective pigging, PCBs and NORMs have been identified as remaining in a limited number of gas transmission lines (Thorne *et al.* 1996).

Regarding disposal, all waste materials and contaminated soils must be handled, stored and disposed in accordance with approved waste management procedures. Properly engineered containment and storage equipment, proper labelling, proper disposal processes with respect to local regulations and effective spill contingency plans should be used (PADP 1996). In general, small quantities of pigging waste are usually accepted by oilfield waste disposal companies, often without conducting detailed chemical analysis (Thorne *et al.* 1996). Asbestos containing coating is removed through a high pressure water jet method, and the water used is collected, filtered and, if associated with coal tar wrap, tested for PAHs, PCBs, and chlorides. In 1996, disposal guidelines for NORMs were not yet established, and PCB disposal guidelines were currently being investigated (Thorne *et al.* 1996).

Recent Findings

Pipelines abandoned in-place should be cleaned to meet all applicable guidelines and regulatory requirements (CEPA 2007). A substantial amount of information now exists pertaining to proper detection, handling and disposal of NORMs, PCBs, and PAHs. Fluids removed from the pipeline should be discharged into tanks to allow settling and proper testing. Though there are many guidelines and standards pertaining to cleaning and proper disposal of pipelines and associated fluids, defining cleanliness, specifically in terms of land use, remain unclear (CEPA 2007). Past studies do provide insight, however, into innovative procedures for disposal and cleaning of pipelines and their related products:

The authors of *Oilfield Abandonment and Soil Restoration in the Netherlands, Experience for the Future* (Kant et al. 2010), discuss new techniques used for dealing with residual substances collected as a result of cleaning procedures. The substances were stored at temporary storage locations where they were then assessed and transported to qualified processing plants. These plants would then work to reduce the toxicity of contaminants via techniques such as anaerobic benzene degradation, land farming, in-situ chemical oxidation and aerobic biodegradation.

The authors of *Innovative Methodology for Cleaning Pipes: Key to Environmental Protection* (Buzelin *et al.* 2008), describe a successful new methodology using chemicals to remove paraffin and asphaltene. It involved the flushing of a chemical product composed of diesel, isopropane, benzene and naphthalene. This method was applied for subsea pipes that were unable to be successfully pigged to meet contaminant levels below Brazilian standards. Such an approach may be viable as a secondary cleaning procedure, ensuring areas along the line unable to be effectively pigged (doglegs, slopes etc) can still be cleaned effectively.

4.2.7 Disposal of pipe material

Background Information

There was no information covering proper disposal of pipeline and pipeline materials recovered from the background readings (PADP 1996, Thorne *et al.* 1996, H.R. Heffler Consulting Ltd. *et al.* 1995).

Recent Findings

In Alberta, waste pipe not containing any hazardous substances can typically be recycled as scrap metal. If the pipe does contain hazardous materials it can either be cleaned to an acceptable standard and recycled, or disposed of at an approved landfill (Swanson *et al.* 2010). If NORMs or PCBs are detected beyond acceptable levels even after thorough cleaning, then disposal should be in accordance with their respective established guidelines (Sections 1.1.2 and 2.2). As an example, in the U.S. no selling or reusing of pipe still containing >50ppm of PCB is permitted, and must be either cleaned to an acceptable level approved by the EPA, or disposed of at an approved incinerator (La Shier 1989).

With respect to pipeline coating materials, specifically coal tar wrap, wrapping the pipe with plastic wrap before removing it from the trench will help reduce flaking and deposition of the material onto the ground (Swanson *et al.* 2010). In a 1996 document entitled: *Utility Manages to Work with Asbestos in Coal-Tar Pipe Wrap* (Falise), research conducted into the health effects of removing coal tar wrap laden with asbestos came to several important conclusions:

- Without the use of power tools or burning apparatus, the non-friable nature of coal tar wrap ensured that its disturbance and removal did not release hazardous amounts of free asbestos into the air;
- The use of special personal protective devices during distribution activities involving wrap removal is unnecessary;
- No extraordinary labeling, packaging or disposal methods are required; and
- Scrap pipe, with the wrap still intact, can be disposed of in a construction debris landfill.

As an alternative to disposal or recycling, pipe cleaned to acceptable standards can be utilized in a number of ways: as bridge guards, support along shorelines, piers for buildings, bridge supports, road foundations, casings, culverts, corrals and cattle guards, centre posts and columns for fence/barns, flag poles etc (Howell 2010).

4.2.8 Abandonment in sensitive ecological areas

Background Information

Sensitive areas such as national and provincial parks, ecological reserves and regionally significant environmentally sensitive areas should be subject to in-place abandonment. In-place abandonment is also the preferred option for native grasslands, forests, wetlands and muskeg. As indicated in the PADP 1996, removal of pipelines in sensitive areas will cause unnecessary disturbances, particularly in muskeg and wetland environments. In wetlands, it is recommended that abandoned pipe be either filled with water or perforated to allow natural invasion of water, with plugs installed along the pipe to prevent drainage and/or contamination (H.R. Heffler Consulting Ltd. *et al.* 1995). In-place abandonment may require some level of activity (*e.g.* spot excavations), and associated impacts such as erosion and slope instability should be mitigated (PADP 1996).

In addition, in-place abandonment should be considered along unstable slopes where, over time, the pipe may act as a structural support, and its removal would damage slope integrity. Removal along slopes could also lead to extensive and expensive remediation requirements (PADP 1996).

Recent Findings

Abandonment in-place along sensitive areas and unstable slopes remains the preferred action (CEPA 2007). However, removal may be the best option in northern areas where soil, groundwater and temperature conditions encourage extensive frost heaving, potentially resulting in surface exposure of the pipeline (Mackay *et al.* 1979). If, for a number of reasons, removal is the only viable option, several mitigation measures provided in the following case studies may be utilized:

In *A Case Study from Abandonment of a Southern Alberta Pipeline* (Swanson *et al.* 2010), clearing, where absolutely necessary, was conducted by hand. To minimize disturbance in treed areas, pipeline segments were cut and pulled from one or both sides of a stand. Furthermore, disturbances in forested areas were mitigated through the use of small, maneuverable bobcats. In native prairie, large pieces of sod were salvaged from the right-of-way and replaced as soon as possible following pipe removal.

In A *Case Study of the Yukon Pipelines Limited* (Roblin 2006), removal in sensitive areas was monitored by a qualified professional, and work crews carried spill cleanup kits. Pipe buried in standing water of wetlands was cut, tested and plugged at both ends. It was then pulled out from the area at one end. One large section of pipe was removed in winter to minimize disturbance to the wetland. Soil samples were taken every 100 meters along the pipeline for visual observations and organic vapour monitoring.

When considering abandonment options in sensitive areas, factors such as burial depth and cleanliness of the pipe should be considered. In frost sensitive northern areas the discontinuation of pipelines may interrupt surface water-ground water interactions, leading to ponding, erosion and channeling along the right of way, whether the pipeline is left in-place or removed (Van Everdingen 1979).

To abandon an NEB regulated pipeline, Section 50 of the OPR states: “An application made by a company under section 74 of the NEB Act for leave to abandon a pipeline or a section of one shall include the rationale for the abandonment and the measures to be employed in the abandonment.”

The NEB will consider the application and approve (or deny) by issue of a Certificate with conditions. The Certificate will not be valid until the conditions are satisfied.

Given this process, it seems reasonable that each project-specific application will examine the land use and environmental implications for the entire system and propose environmental mitigation measures that satisfy the NEB. The environmental threat of an abandoned pipeline seems similar to that of the operating pipeline. The consequences of leaks are removed but the risk of other physical phenomena such as river scour, channel migration, floods, right-of-way erosion, landslides, etc., continue.

The process of removing a buried pipeline may create as much or more environmental disturbance as pipeline installation. Most pipelines are likely to be abandoned in place except where current or reasonably foreseeable land use dictates removal. During abandonment, site-specific study will identify appropriate environmental protection measures.

4.2.9 Abandonment under water bodies

Background Information

In general, in-place abandonment is the preferred approach for pipelines abandonment under water bodies (PADP 1996). Left in-place, the pipeline should be as clean as possible, and caps and plugs should be strategically positioned to mitigate contamination threats from trace materials along the rest of the line. If the pipeline has the potential to float it should be either perforated, with caps and plugs in place to protect from contaminants, or filled with concrete. If the line is to be removed through excavation, mitigation measures will be identical to those used in initial construction. Removing the pipeline may be required if threats of future exposure from excessive erosion seem likely (PADP 1996). It may even be prudent to remove the pipe at sag bends under threat of exposure from horizontal channel migration (Heffler Consulting Ltd. *et al.* 1995).

Recent Findings

Limited new information was acquired regarding pipeline abandonment under water bodies. In *A Case Study from Abandonment of a Southern Alberta Pipeline* (Swanson *et al.* 2010), they found that, during abandonment, the 273 mm O.D. pipeline segments could be successfully pulled from watercourses. The study also mentions the Alberta floods in 2005, where numerous creaks flooded their banks, leaving a number of pipelines exposed. Sudden exposure of pipe as a result of such scenarios, or from gradual erosion, could pose hazards for water recreation (*e.g.* obstruction, hydrology changes etc).

4.3 Geotechnical

The geotechnical section of this report presents a discussion of geohazards or "natural hazards," and focuses on the two most active natural hazard types; geotechnical (soil or slope related) and hydrotechnical hazards (surface water related). Other types of natural hazards are discussed as appropriate. Section 6 presents a summary of the key documents forming the foundation of this report. The relevant issues are summarized in Section 3. In this section a summary of key findings from the relevant literature and experience is presented.

The literature search yielded 16 documents that were geohazard-related; however, none particularly addressed geohazards for onshore pipeline abandonment. Some papers detailed characteristics of geohazards and a few were related directly to geohazard management. To supplement these sources, the book Geohazard Management in Pipeline Geo-Environmental Design and Geohazard Management, published by the American Society of Mechanical Engineers, was consulted as a reference.

A natural hazard, depending on the nature of the hazard and the scale of the occurrence and the prior condition of the right of way and pipeline can result in the following:

- No significant effect on the pipeline (i.e. a 0.5 m surface slide occurs but the pipeline is buried 4 m deep),
- Pipeline exposure (i.e. concentrated flows occur and erode 1.5 m of soil from a slope and the pipeline was buried 1 m deep), and

- Puncture of the pipeline (i.e. a large scale landslide occurs and breaks the pipeline).

As a consequence of other factors (such as pipeline removal or corrosion) the collapse of the pipeline and the surrounding soil can also occur. The collapse failure mode is not thought to be caused by a natural hazard, but by other factors leading to a condition where the soil has a void to collapse into. Soil collapse is a consequence for some land use, and could lead to other types of consequences.

Information regarding the mechanism of pipeline collapse is scarce, excepting the 1996 Geo-Engineering study (Geo-Engineering (MST) 1996) completed for the NEB. More information exists on the occurrence of exposure and puncture, almost no information is specifically for abandoned pipelines, while most information comes out of integrity work related to active pipelines.

The main geohazard concerns were identified in Section 3.1, Past Studies. These have been broadly categorized into those that could cause pipeline exposure and/or puncture, or conditions where collapse could occur. Each is associated with unique concerns in terms of land use and/or environmental consequences.

In addition, each of pipeline exposure, puncture and collapse is then a leading factor for the development of the next stage of degradation. For example, the exposure of a pipeline can increase the probability of pipeline puncture from geohazards, corrosion and outside forces. This relationship of each condition enhancing the likelihood of the next occurring is not specifically addressed in this section, although Event Trees relating causes and consequences could be developed to aid in understanding of these types of scenarios (Discussed in Section 5.1.3). To develop general guidance on pipeline abandonment, both the direct consequence of the geohazard, and the further effects that can be linked to the initial hazard, should be considered, such as is shown in Table 2: Retirement Options Matrix.

The understanding of these topics was developed based on a review of the past studies summarized in Section 3, and by careful review of literature and knowledge gained by experience of our subject matter experts (SMEs).

General Comments on Geohazards

Geohazard occurrences are largely spatially controlled. They are concentrated at: rivers, slopes, water bodies, crossings and other distinct locations. Geohazards are all principally controlled by local factors such as soil type, access to moisture and local temperature/insulation effects. Thus, any abandonment plan must review geohazards at distinct locations. Forty distinct geohazards (Rizkalla et al. 2008) are categorized for assessment as part of management of hazards for active pipeline integrity. The types of geohazards present on a particular pipeline are a function of the natural attributes of the right of way and are thought to largely persist once product is no longer flowing in the pipeline; the differences are related to the consequences.

Geohazards can be categorized in to the following general headings (after Rizkalla et al. 2008):

1. Mass movements (geotechnical)
2. Hydrotechnical
3. Seismic
4. Surface or subsurface soil erosion (normally associated with slopes)
5. Freezing
6. Thawing of permafrost
7. Geochemical
8. Volcanic
9. Others (normally associated with unique geological settings; volcanic activity, Karst, desert conditions)

The most active geohazards for typical pipelines are; hydrotechnical, surface or subsurface erosion and geotechnical (Leir 2009). Hydrotechnical hazards are associated with channelized flow of streams and rivers. The mechanism of erosion varies with river energy and the soil through which the river flows and can manifest as scour, channel degradation, bank erosion, stream encroachment and avulsion. Surface erosion of the ground varies with rainfall, channelization of local water, soil types, slope and vegetation. Geotechnical hazards are associated with various types of earth/mass movements, which vary with soil types, groundwater and changes to either the groundwater or the loading of the slope.

4.3.1 Exposure

Understanding of issue and existing information

In order to provide context for the likelihood of pipeline exposure following abandonment, an examination of the occurrence of pipeline exposure due to geohazards on active pipelines was used as a proxy. It can be expected that the rates of exposure could be higher for an abandoned pipeline due to the lack of maintenance or active visual inspections, eventual loss of buoyancy control where installed and frost heave of pipe without product within the pipeline. Pipeline exposure in an area where buoyancy control is needed is thought to be controlled by the failure of the control measures, if no other action is taken. No literature was found on the potential for frost heave to expose an abandoned pipeline, but culverts and pipelines with product near ambient temperature could be considered a proxy for further study.

The effects of pipeline exposure are threefold; interference with land use, degradation of the pipe or coating, and becoming a cause for further degradation by puncture/collapse.

Based on reviews of various pipeline systems in Western Canada (Leir 2009), the annual pipeline exposures/impact rates for active pipelines was: 1.4 exposures/impacts per 1,000 km of pipe. Of these exposures/impacts, 1.2 were due to hydrotechnical hazards and 0.2 due to surface erosion/geotechnical hazards (Leir 2009 groups surface erosion/geotechnical hazards as geotechnical hazards).

The main hydrotechnical hazard types include (Leir 2009): scour, degradation, bank erosion, encroachment and avulsion. Scour occurs in channels that are deepened where water flow becomes concentrated by obstacles in the stream; therefore, locally increasing erosion and reducing the depth of cover over a pipeline. Degradation, which is probably the most common hydrotechnical hazard leading to pipeline exposure, is the natural lowering of the channel bed that occurs when sediment supply is decreased or the erosive capacity of the stream is enhanced. Vertical erosion rates are estimated at an average 20-30 mm per year when typical flow regimes and storm events are considered together. When this erosive force is focused on the horizontal migration of the stream, bank erosion occurs, most often on the outside curve of the channel. If pipelines run parallel to a river or stream, encroachment may occur should the stream migrate to intersect the pipeline. Again, this is common at the outside curve of bends. Finally, stream avulsion can lead to pipeline exposure when the existing channel is abandoned for another route, one that intersects the pipeline. Avulsion occurs most often on debris flow fans or as a result of flooding within flat floodplains. The rate of pipeline exposure due to these hazards should not be affected by abandonment of the pipeline or the filling/plugging of the pipeline.

Surface water erosion includes erosion of the backfill directly above the pipeline or of other areas on the right of way that were cleared or disturbed for pipeline installation. The occurrence of this mode of exposure is thought to be generally increased upon abandonment, since the inspection will be reduced or eliminated. If the pipeline is removed from a slope by excavation, re-establishment of vegetation will be required to reduce the amount of erosion on the slope.

Furthermore, wind erosion and deposition can reduce or increase the cover thickness over pipelines. The effects of wind erosion are enhanced where topography is more pronounced depending on soil texture and where vegetative cover is thin.

Mass movements can sometimes result in pipeline exposure (although they normally would result in development of strain and puncture of the pipeline), especially at river banks or if the soil flows from around the pipeline. The rate of exposure is unlikely to be changed by abandonment.

4.3.2 Puncture

Understanding of issue and existing information

Similar to pipeline exposure, an estimate of the occurrence of puncture during abandonment can be estimated by the rate of pipeline failure due to geohazards. In an active pipeline, the internal product pressure has the effect of provided a bursting pressure, which may decrease the likelihood of a puncture without product as compared to an abandoned line. The effects of the puncture are much less significant without the possibility of liquid or gas product leaks or ruptures. However, a puncture would allow water access into and out of the pipeline, which in turn may produce flow in the pipe (and potentially a pathway for residual contamination or water flow) and internal corrosion. In Canada, the annual rate of pipeline failure due to geohazards is between 5.4 to 1.6 x 10^{-3} per 1,000 km of installed pipelines (Rizkalla et al. 2008). These statistics indicate that geohazards are much more likely to result in pipeline exposure rather than puncture.

The geohazard that causes most of the punctures is mass movement (landslide, debris flows or rockfall) due to overstressing of the pipeline. Although the rate of pipeline failure is much less for geohazards than other failure mechanisms, the cost of a failures due to geohazards is high (Porter et al. 2004) due to the significance of the individual events. Following abandonment, the consequences of a puncture resulting from geohazards should be about the same as for other causes of puncture.

4.3.3 Collapse

Understanding of issue and existing information

Complete pipeline collapse is not typically encountered in active pipelines, and is unlikely to result from a geohazard.

If external loading exceeds the pipe capacity, at crossings or due to corrosion of the pipe reducing its load carrying capacity, the pipe could collapse. If the pipeline is removed from the ground, or completely corroded a void would be created within the ground, which could collapse. These two scenarios create a conduit in the soil, or permit the above soil to collapse into the void. The 1996 (Geo-Engineering 1996) study undertaken for the NEB outlined the potential effects of voids and the resulting surface effects.

There have been studies conducted in attempt to determine the effects of pipeline collapse on the ground surface and establish whether significant subsidence will result, a significant subsidence is one that would result in damages to person and property. A 1996 report prepared for the Pipeline Abandonment Committee by Geo-Engineering (M.S.T.) LTD. modelled conditions wherein significant soil cover collapse would be observed. The results of the study concluded that it is improbable that substantial subsidence would occur simultaneously over a long stretch of pipe and the likely scenario would be slow loss of ground into a perforated pipe. The study also concluded that, depending on soil bulking factor and for a 1 m depth of burial, 300 mm diameter voids are the maximum size that would result in little or no subsidence. The study also indicated that more research is required with regards to soil-pipeline interaction and the effects of time on the system. It is expected that, in the long term, any pipeline left in place would eventually degrade to the point that a void exists in the ground.

4.4 Engineering

4.4.1 External Corrosion

Data from Literature

Very little information was found in the literature on the topic of external corrosion of abandoned pipelines and the inevitable collapse of these pipelines as the external corrosion progresses. On the other hand, there is a fair amount of data on underground corrosion that is useful in the assessment of this issue. The National Bureau of Standards [now referred to as the National Institute of Standards and Technology (NIST)] funded extensive research on this topic in the 1950's and this work is summarized in a report that is currently available through NACE International [Romanoff 1957]. In this research, coated and uncoated coupons of a number of different steels were exposed under freely corroding conditions in soils throughout of the United States. While it is difficult to summarize the large body of work in this report, some of the significant findings include:

- Soil corrosivity increases with decreasing pH
- Soil corrosivity increases with decreasing resistivity
- Pitting rates follow a power law, with an exponent that is generally near 0.5 and varies with soil properties

With respect to soil resistivity, Table 2 shows that soils having resistivities less than 1000 ohm-cm are generally considered to be very corrosive, while soils having resistivities greater than 10,000 ohm-cm are considered to be essentially not corrosive.

Table 1. Soil Corrosivity vs Soil Resistivity [Beavers, 1998]

Soil Resistivity, Ω-cm	Corrosivity
0-1000	Very Corrosive
1000-2000	Corrosive
2000-10,000	Mildly Corrosive
> 10,000	Progressively Less Corrosive

The California State Department of Transportation [Anon 1993] performed an analysis of data from perforated culverts and observed a similar correlation between soil corrosivity and the pH and resistivity of the soil. They developed an algorithm relating these factors to the time of perforation of a 52 mil culvert:

$$\text{Years to Perforation} = 13.97[\text{Log}_{10}R - \text{Log}_{10}(2160\text{-}2490\text{Log}_{10}\text{pH})]$$

A linear corrosion rate was recommended by the authors for extrapolation to thicker culverts. This assumption is questionable, albeit conservative, if the culverts perforate by pitting, which is likely, because the power law exponent for pitting is generally less than one. Figures 1 and 2 show the predictions for perforation of a pipeline, by corrosion, for various soil resistivities and wall thicknesses. The most striking conclusion from this analysis is that the predicted perforation times are very long, > 50 years, for even moderate pipe wall thicknesses. This prediction does not appear to be consistent with pipeline industry experience in which pitting perforations are seen in much shorter time periods for pipelines with inadequate or no cathodic protection.

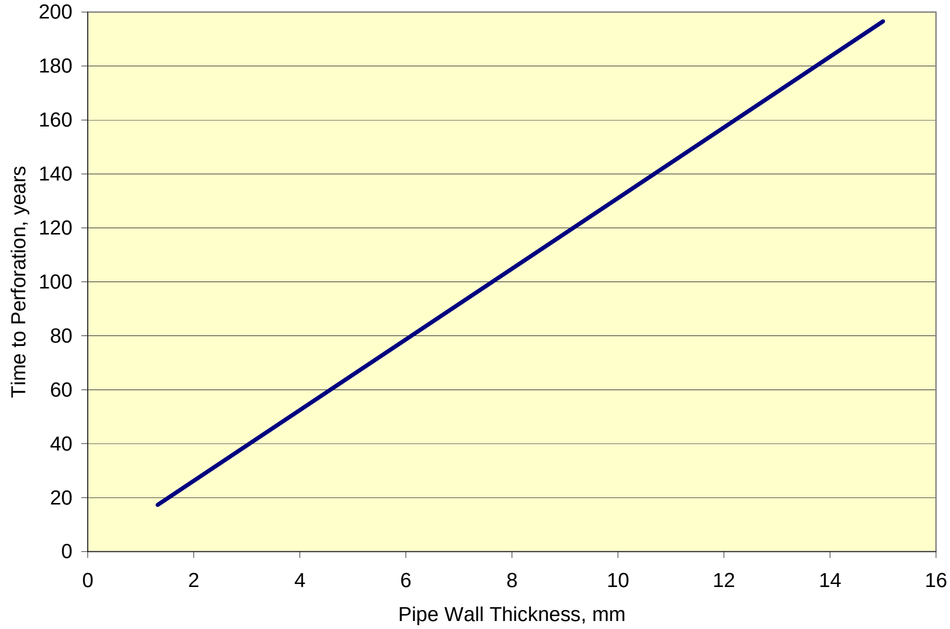


Figure 1. Time to perforation as a function of pipe wall thickness for a soil resistivity of 1000 ohm-cm and a soil pH of 7.

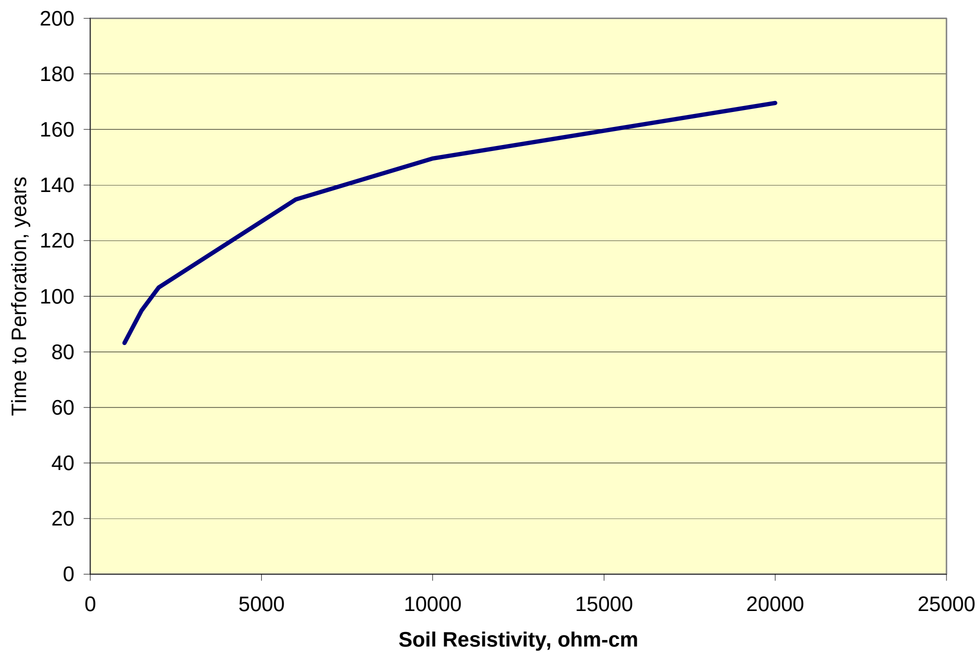


Figure 2. Time to perforation as a function of soil resistivity for a pipe wall thickness of 6.35 mm and a soil pH of 7.

While the time to perforation predictions from the culvert model appear to be unreasonably long for typical pipeline wall thicknesses, the parameters used in the model appear to be sound based on the extensive body of underground corrosion data. Therefore, a reasonable path forward is to analyze the underground corrosion data available in the literature to optimize the model for general corrosion of the thicker pipeline steels. This model could then be incorporated with an actual collapse model (described below) to predict the time to collapse from external corrosion as a function of soil properties and pipeline dimensions.

Once through-wall perforations occur in an abandoned pipeline, the pipeline is likely to fill with groundwater. This could promote internal corrosion that could ultimately contribute to pipeline collapse. While no data were found on this topic in the literature, the mechanism of aqueous corrosion, along with related literature, were used to evaluate this issue. Two cases were considered; complete filling of the pipeline with groundwater (Case 1), such as in a swamp, and partial filling (Case 2). For Case 1, it was assumed that the pipe fills with aerated groundwater. Since the solubility of oxygen in water is low (< 8 ppm), the oxygen in a pipeline will be consumed rapidly for typical corrosion rates. For example, the oxygen in a 24-inch diameter pipeline will be consumed in around one week at a corrosion rate of about 0.1 mm/y. After the oxygen is consumed, the corrosion rate will drop to negligibly low values. Anaerobic bacteria may accelerate the corrosion rate somewhat, but significant damage would not be expected based on measured corrosion rates for deep steel pilings (Beavers 1998), or buried subsea artifacts (J A.

Beavers, G. H. Koch, and W. E. Berry, "Corrosion of Metals in Marine Environments," Metals and Ceramics Information Center, MCIC Report 86-50, 1986) Furthermore, resupply of oxygen in the pipeline would be very limited unless there were a large number of large holes present in the pipeline.

Case 2 is somewhat more problematic in that the oxygen in the vapor space in a partially filled pipeline could promote continuous internal corrosion of the pipeline under aerated conditions. The most severe corrosion would likely occur at the liquid air interface where the water volume was small, because of the associated large air volume. However, under these conditions, the corrosion would be localized to the bottom of the pipe and the resulting collapse would be minimal.

The conclusion of this analysis is that external corrosion of abandoned pipelines is likely to be the largest contributor to ultimate collapse.

4.4.2 Structural Integrity

Data from Literature

No information was found in the literature on the topic of structural integrity of abandoned pipelines and on methods for assessing their collapse when external corrosion reaches a critical value. On the other hand, API 579-1/ASME FFS-1 provides methods for assessing the fitness for service of pipe with general or local metal loss and external pressure loading that could be applied to abandoned pipelines with external pressure loading from soil. Paragraph A.4.4 in Annex A of this standard provides equations for calculating allowable thickness, maximum pressure, and stress on cylindrical shells subject to external pressure. Paragraph B1.4 in Annex B1 of this standard provides guidelines for performing stress analysis to protect against collapse from buckling.

The methods in API 579-1/ASME FFS-1 may not be directly applicable to pipeline abandonment as written because they were developed for application to pressure vessels and piping in operating facilities. A detailed review and evaluation of these methods is needed to assess their applicability to pipeline abandonment issues.

5 RECOMMENDATIONS FOR FURTHER STUDIES

Based on the assessment of the literature reviewed as outlined in Section 4 above, this section recommends various research projects which could be conducted to address the knowledge gaps identified for pipeline abandonment issues.

5.1 Environmental & Land Use

5.1.1 Detection of Residual Contamination

In the opinion of the SMEs, testing protocols (both field and laboratory) for hydrocarbon contaminants (and other reasonably foreseeable elements) in soil and/or groundwater is quite well established. An area of deficiency relates to practical methods to measure the extent of residual hydrocarbons inside a segment of buried pipeline.

While there are well known practices for testing and managing PCBs, a protocol for PCB detection within a buried pipeline is not readily available.

Similarly, standard practices for detection of NORM and handling/disposal of NORM-contaminated material is relatively well known in some areas of petroleum industry activities. However, this is a potential hazard that is not well documented in connection with pipeline abandonment.

Recommendations made during the previous abandonment studies continue to be valid. These recommendations include:

- Estimation of the quantities of contaminants that might be released by an abandoned pipeline (Thorne *et al.* 1996).
- Research contaminant types and volumes relative to different pipeline products and locations within the distribution system (Thorne et al. 1996).
- Research the systematic protocols for PCB swab testing (Thorne et al. 1996).
- Review study conducted by US Institute of GAS Technology on trace contaminants in natural gas (Thorne et al. 1996).
- Investigate statistical analysis approaches for determining PCB concentrations throughout a pipeline (La Shier 1989).
- Research EPA findings on development of an appropriate methodology to quantify residual pipe contamination and development of a statistical model for PCB characterizations (*e.g.* "moving average" approach) (Linz 1991).

- Research the use of swab tests to develop surrogate contaminants that are representative of the residual contaminant load of various types of pigged and cleaned pipe in order to reduce assessment risk and cost (Thorne et al. 1996).
- Research PCB physical and chemical characteristics in natural gas environment as they are yet unstudied (Linz et al. 1991).
- Transport of PCBs as a component of various pipeline fluids is not well known (Linz *et al.* 1991).
- Research study by GRI and NIST into predicting PCB migration the physical/chemical controls that influence it (Linz *et al.* 1991).
- Research soil/water PCB partitioning study conducted by GRI and Battelle Pacific Northwest Laboratories (Linz *et al.* 1991).

Current Recommendations:

Develop practical testing protocols to accurately quantify residual contaminants remaining inside a section of buried pipe following standard cleaning procedures. The purpose of developing standard sampling protocols is twofold: for one, the chosen methodology would serve to provide an accurate representation of the nature, extent and distribution of contaminants along the pipeline; secondly, such a universal approach would provide user-friendly guidelines for companies, and ensure consistent sampling results. Such standard protocols would be developed to determine the initial likelihood of PCB and NORM contamination in the pipeline. In doing so, NORMs and/or PCBs would either be included or excluded from further testing.

Scope:

Standard testing protocols should be developed in consideration of standard practices for detection of hydrocarbons, PCBs and NORMs in pipelines. In order to integrate these contaminants into a standard testing protocol, three separate studies should be conducted:

- Methods to accurately quantify residual hydrocarbons along an abandoned pipeline.
- Develop standard practices for detection of PCBs where suspected in abandoned pipelines.
- Standard practices for detection of NORM-contaminated pipe. (This study could be limited to the pipelines regulated by the NEB. Past experience suggests that NORM contamination in oilfield pipe, fittings and tanks is more likely to be found in upstream oil and gas activities than in the transmission and distribution systems regulated by the NEB).

Expected Results:

In recommending further research into the environmental effects of pipeline abandonment, the development of a standard testing protocol takes precedence. Many decisions regarding the management and handling of abandoned pipeline hinge on the efficacy and accuracy of contaminant testing. For example, establishing a standard testing protocol may lead to:

- An accurate indication of the potential concentrations of contaminants to be transported down a section of abandoned pipeline as a result of the conduit effect;
- A greater understanding of the nature, extent and distribution of contaminants, which is the first step in developing formal risk assessment tools modelling the fate and effects of detected contaminants in an abandoned pipeline;
- Consistent results, allowing statistical studies of such results to be compiled from various abandonment projects and, over time, lead to the development of a contaminant database with the establishment of categories of expected residual contaminants based on the pipeline product and locations along the pipeline system;
- Greater support for providing an indication of effective cleaning methods; and
- Guidance for decision making on locations for pipeline abandonment in-place.

Length of Time to Conduct Research:

1 year of field work to conduct research on a representative sample of pipeline types and sizes would be required.

Types of Organizations to Conduct Research:

Oil and gas pipeline operating companies to donate segments of pipeline to conduct an assortment of sampling techniques.

Environmental consultants to provide direction on appropriate locations for sampling.

Accredited environmental laboratories to conduct analysis.

Expected Costs

Costs associated with developing a practical and accurate sampling method for hydrocarbon related contaminants are estimated at $100,000.

Costs associated with developing a practical and accurate detection method for residual PCBs in pipelines are estimated at $15,000.

Costs associated with developing a practical and accurate detection, handling and disposal procedure for NORMs are estimated at $25,000.

Standard Pipeline Products List

Background
Liquid petroleum products can consist of a complex mixture of paraffinic, cycloparaffinic and aromatic hydrocarbons covering carbon chains ranging from C1 to C60+. The composition varies depending on the source of crude and/or the refining process. Some products can contain minor amounts of sulphur, nitrogen and oxygen compounds as well as trace amounts of heavy metals such as nickel, vanadium and lead. Natural gas is a complex combination of hydrocarbons consisting of saturated aliphatic hydrocarbons predominately consisting of methane and ethane but such that constituent composition may vary.

Recommendation:
Initiate a study to identify compounds to be tested for in soil and water as a result of a pipeline leak at the abandonment phase.

Scope
A review of products shipped through NEB regulated pipeline systems. The study should include a thorough review of the Material Safety Data Sheets (MSDS) for all products shipped as well as for products that could enter the pipeline as a result of the operation and at abandonment of the pipeline system.

Expected Result
The development of a standard list compounds expected to be found as a result of a pipeline leak. The research should determine the extent to which the list can be applied to abandoned pipelines. A detailed review and evaluation of the list is needed to assess the applicability to pipeline abandonment issues.

Project Duration
The study could be completed within one month.

Types of Organizations that Could Conduct the Research
This study could be conducted by environmental consultants in cooperation with pipeline operating companies.

Expected Cost of the Research
The proposed study is expected to cost approximately $25,000.00

5.1.2 Environmental Standards

Current Recommendations:

In SMEs opinion, further enhancements of the current standards on soil and groundwater quality are beyond the scope of issues that warrant effort by the Pipeline Abandonment Physical Issues Committee (pipeline abandonment committee).

Ultimately, standards for pipeline abandonment could be proposed but currently there is insufficient practical experience in accurately measuring the presence and quantity of contaminants remaining in a section of abandoned pipeline to consider general or specific environmental standards at this time. It is recommended that NEB regulated pipelines use CCME standards to assess remediation success.

5.1.3 Risk Assessment

Recommendations made during the previous abandonment studies continue to be valid. These recommendations include:

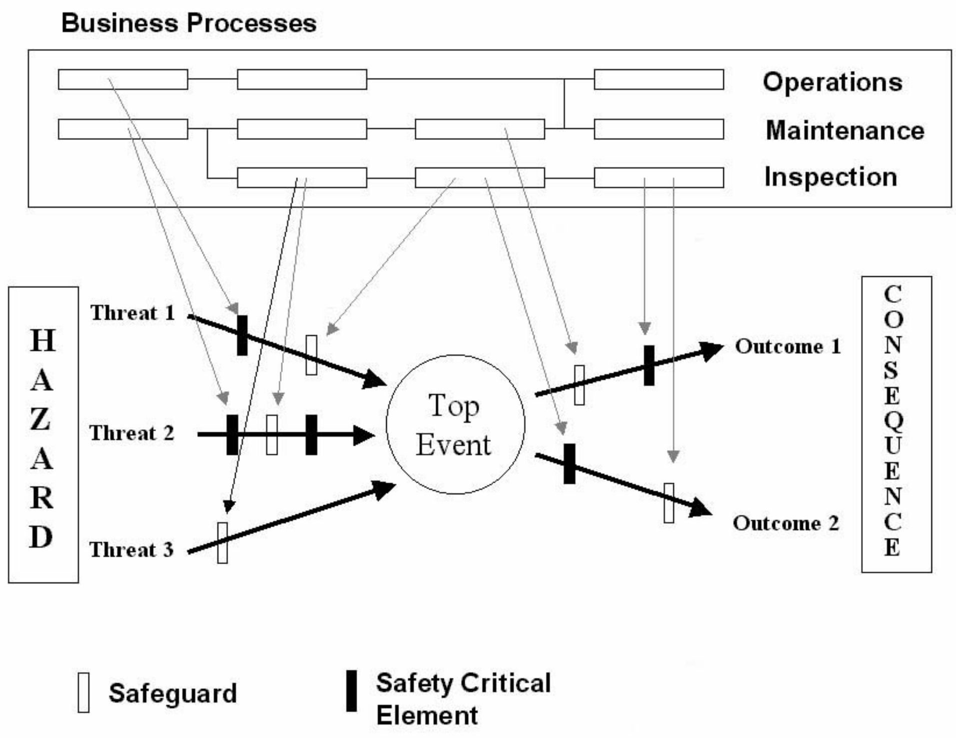
- Research and refine land use categories as part of the development of the risk based site specific assessment process (CEPA 2007).
- Research the impacts of new treatment chemicals being marketed for use in the oil and gas industry, particularly as they relate to pipeline abandonment in-place (Thorne *et al.* 1996).
- Further research into contaminant properties and their potential environmental impacts (Thorne *et al.* 1996).

Current Recommendations:

Background

Given the variability of potential causes of pipeline collapse and the consequences that vary with location and other local environmental factors, it is suggested that an event and consequence analysis be used as a tool to identify scenarios and consequences related to pipeline abandonment.

One method which may be adapted to pipeline abandonment is the Bow-Tie analysis illustrated below. In the centre of the diagram is the ‘Top Event’ or process hazard. To the left are the barriers or safeguards that aim to prevent the top event from occurring, to the right are all the safeguards that aim to mitigate the potential consequences from the top event.



Safeguards can be varied in nature from personnel with relevant experience, to training, to operational procedures, and so forth. Using this approach it is critical to know the status of each safeguard in real time to support decision making.

It can readily be seen that by analyzing all potential top events and quantifying all potential outcomes for all types of losses a picture of the risk exposure at any point in time can be built up. Safeguards to the left of the top event affect the likelihood that the event will take place, in Quantitative Risk Assessment (QRA) terms, the frequency of the event. Those to the right impact the potential consequences of an event and can increase or reduce the severity of a top event.

Objective and Scope

The objective of this research would be to identify the various scenarios and related consequences of pipeline abandonment events and identify potential consequences of those events.

Expected Result

The research would determine the potential risk exposure for various events and outline potential safeguards to reduce the frequency and/or consequences of a particular event.

Project Duration

The project could be completed within three months.

Types of Organizations that Could Conduct the Research
This research could be conducted by risk consultants.

Expected Cost of the Research
The proposed research is expected to cost approximately $50,000.

5.1.4 Conduit Effect

No examples of an abandoned pipeline acting as a conduit for water movement were found in the literature review. The potential for a pipe abandoned in place to become a conduit for water movement was discussed in Section 3.9 of the PADP 1996. If the abandoned pipeline is clean, the potential environmental risks could be related to draining wetlands or, conversely, flooding inappropriate land areas or to transport soil material inside the pipe to a down slope location where it may escape and cause impacts. If the pipe is not clean there may be a risk of transporting contaminants.

In order to address these potential issues, it is assumed that the abandoned pipe would be segmented at appropriate locations. Both the CAPP 2002 Guidelines document and the CEPA 2007 Pipeline Abandonment Assumptions document refer to Table 3-1 of the PADP 1996 for determining the appropriate locations where segmentation and plugs are recommended which remain valid today. Impermeable materials such as concrete, polyurethane foam or soil are still reasonable materials to create plugs in the pipe.

In the case of pipeline removal, water pathways through the uncompacted pipeline trench material must be prevented or interrupted. The principles governing the locations of trench breakers are the same as those governing the locations of plugs for pipelines abandoned in place.

The occurrence of the conduit effect on the outside of an abandoned pipeline is not seen as being any different than for an operating pipeline. If it was not an issue previously it should not be an issue when the line is abandoned in place.

No additional studies are recommended with respect to the potential conduit effect although this issue could be monitored as part of the study recommended in section 5.2.4 below.

5.1.5 Decomposition of Pipe material

Recommendations made during the previous abandonment studies continue to be valid. These recommendations include:

- Quantification of subsidence threats for large diameter pipelines, and the possible development of algorithms to model structural collapse of pipelines (CEPA 2007).

- Study leaching potential of coal tar coatings, and identification of the specific PAHs that may be released into the environment from the degrading coatings (Thorne *et al.* 1996).
- The potential environmental risks from asbestos left in-place should be further assessed (Thorne *et al.* 1996).
- Inspect a representative number of abandoned lines to observe rates of corrosion, internal contamination from pipeline residues, structural integrity and soil contamination (H.R. Heffler Consulting Ltd. *et al.* 1995).
- In a 1974 document entitled: Recent Developments in the Use of Mine Waste of Subsidence Control (Allen *et al.*), the authors describe the effectiveness of using sediment slurries for hydraulic filling of abandoned mines. Perhaps further research could be conducted into the applications of this technique for in-place pipeline abandonment.

Current Recommendations:

The mechanism, rates and effects of pipe corrosion warrants engineering study while considering contamination of soil or groundwater by pipe coatings and their degradation products is worthy of consideration. While not likely to be widespread or dramatic, it should not be ignored. A study of the leaching potentials of pipe coatings (especially older materials such as coal tar coatings) is warranted. Consideration should be given to the environmental and human health effects of the chemicals, the rate and nature of chemical decomposition, potential for soil and groundwater transport and recommendations leading toward improved abandonment/disposal practices.

Scope:

Study leaching potential and associated human health and environmental effects of the contaminants released from coal tar coatings. A theoretical understanding of the potential for leached contaminants to move through various soil and groundwater regimes, as well as the human and environmental consequences of such contamination, should be established. Concurrently, laboratory testing of the structural integrity and the rate and nature of chemical decomposition of coal tar coatings under simulated field conditions should be undertaken.

Expected Results:

A greater understanding of the nature and rate of coal tar wrap decomposition, dispersal of leached chemicals in the surrounding environment and the potential human and environmental effects of leached contaminants will contribute to the development of formal risk assessment models with respect to identifying the fate and effects of detected contaminants in an abandoned pipeline with coal tar coating; and the establishment of safe handling and disposal procedures / recycling options for pipelines coated with coal tar wrap.

An understanding of soil and groundwater mechanisms suggests that solution and transport of metal ions in the environment resulting from corroding pipe is worthy of thought, but is almost certainly not likely to be a widespread issue. The SMEs suggest this is a topic that can be deferred for future consideration.

Length of Time for Research:

3 – 6 months

Types of Organizations to Conduct Research:

Charter Coating, of Calgary Alberta, is an example of a company able to perform external coating evaluation tests, and is capable of undertaking integrity tests on coal tar coating to determine the rate of coating decomposition.

Analyzing the dynamics of decomposed coatings in soil and groundwater, and the associated human and environmental effects, should be undertaken by a company or companies specializing in environmental chemistry and human health.

Expected Costs:

Costs associated with undertaking integrity tests on coal tar coatings is estimated at $15,000.00

Costs associated with the study of leaching potential of coal tar coatings, and identification of contaminants that may be released into the environment from the degrading coatings is estimated at $10,000.00.

5.1.6 Cleaning methods and disposal of cleaning fluids

Recommendations made during the previous abandonment studies continue to be valid. These recommendations include:

- If pipe is going to be reused for alternative purposes, further research should be conducted in order to determine the appropriate cleanliness requirements for the intended use (Thorne *et al.* 1996).
- The development of a pigging report including information on types and quantities of pipeline scale (Thorne *et al.* 1996).
- The evidence which regulatory authorities will accept as being sufficient proof of cleanliness in terms of the residual volume of contaminants requires adequate definition (Thorne *et al.* 1996).

- There is currently insufficient data available to make a reasonable estimate of the maximum volume of contaminants that may remain in a pigged line (H.R. Heffler Consulting Ltd. *et al.* 1995).
- Adequate standards of cleanliness should be attained through accepted test procedures. Testing water slugs pushed through the line could prove a useful technique (H.R. Heffler Consulting Ltd. *et al.* 1995).
- Cleanliness parameters should be established through the development of a model recommending appropriate levels of cleanliness for abandonment (H.R. Heffler Consulting Ltd. *et al.* 1995)

Current Recommendations:

To the best of our knowledge, no published reports or field trials of pipe cleaning are available. Although such a study is recommended, it is suggested it be led by qualified engineers and pipeline operators.

Scope:

An engineer led study should be undertaken to determine effective cleaning methods in an attempt to determine cleanliness parameters for either abandoning pipeline in place, or removing sections for reuse or disposal.

Expected Results:

The development of cleanliness standards following determination of effective cleaning procedures and establishment of an accurate and acceptable sampling protocol are expected to assist in:

- Establishing safe handling and disposal methods for pipelines;
- Providing an indication of the effectiveness of cleaning operations along a given length of pipeline;
- Removing the obscurity in determining "how clean is clean" and streamline the abandonment process in a safe and responsible manner;
- Determining the environmental suitability of the cleaning compounds;
- Handling and disposal of wax, waste petroleum products, spent cleaning compounds, etc;

- The environmental safety of all practices (risk of spills, emergency preparedness, worker and public health, etc); and
- Developing achievable cleanliness standards for pipe to be abandoned in place or removed for reuse or disposal.

Length of Time for Research:

1 -2 years

Types of Organizations to Conduct Research:

Pipeline operating companies;

Materials Engineers;

Companies specializing in environmental chemistry and human health.

Expected Costs:

Costs for developing such standards are estimated at $150,000 to $200,000. The costs associated with undertaking this research result from both the necessity to involve a range of expert knowledge and opinion and the extensive period of time potential required to establish collective agreement on what contamination levels constitute a clean pipe.

5.1.7 Disposal of pipe material

Current Recommendations:

Until standards have been developed to determine acceptable concentrations of residual contaminants, recommendations for reuse and/or disposal studies cannot be made. Current options for disposal of pipe materials include complying with the requirements of a government approved landfill.

5.1.8 Abandonment under water bodies

NEB regulated pipelines are found under all types of water bodies; streams, lakes, irrigation canals, and others. (No consideration has been given in this report to offshore pipelines, although onshore pipelines crossing a large lake employing marine lay methods are quite feasible.) Water saturated soil; such as muskeg or flood irrigated lands, could be included in this discussion as well.

Again, it is assumed that most pipelines under any water body will be abandoned in place – after due consideration by way of Certificate approval. In this case, the environmental implications are related to loss of buoyancy control (*i.e.* pipe flotation) or exposure by other means. As well, since most streams are located at the bottom of a slope, the risk of surface erosion or the implications of material transport and discharge via the buried pipe acting as a conduit need to be recognized.

There will however be instances where the risk of abandonment in place dictates special treatment. Cutting and capping the pipe at each side of the water body will be warranted in some cases, as will removal of some or all of the pipe in anticipation of stream bed scour or lateral channel migration. In other cases the pipe section under the water body could be filled with cement as a permanent way to prevent flotation. This is likely to be used in special cases but it has to be admitted that, a cement filled pipe section that is exposed, could be a barrier to fish movement or to human use and enjoyment of a stream.

Removal of the underwater section of a pipeline seems a last resort since this practice could result in significant disturbance to the stream. Since this is likely to be a very infrequent practice, no comprehensive studies are suggested. There have been a few cases where a length of buried pipe has been pulled from the ground with essentially no surface disturbance, other than the locations where the pipe has to be exposed at each end necessitating land disturbance and reclamation at those locations. If successful, this technique would be especially attractive at watercourse crossings.

Current Recommendations:

It is recommended that an engineered led study to investigate techniques to remove sections of buried pipeline resulting in little to no surface disturbance with respect to abandonment under water bodies as well as sensitive ecological areas.

Scope:

Engineering field tests to determine the diameter and length of pipelines and the extent to which they can be pulled from the ground should be conducted.

Potential environmental effects associated with pulling pipe from underneath water bodies for consideration include alterations of stream hydrology as a result of subsidence and structural instability of the bed and bank complex. Potential environmental effects associated with pulling pipe from beneath sensitive ecological areas and wetlands for consideration include subsidence and terrain instability, as well as channeling of surface and subsurface water along the trench and associate subsidence and/or erosion.

Expected Results:

Recognizing the potential environmental effects associated with pulling pipe from under water bodies and sensitive ecological areas could lead to:

- The establishment of mitigation measures in response to such effects; and
- The establishment of best-practices for abandoning a section of pipeline under a water body or sensitive ecological area.

Length of Time for Research:

1-3 years to conduct field tests at a variety of locations with various diameters and lengths of pipeline.

Types of Organizations to Conduct Research:

Pipeline operating companies in cooperation with environmental consultants.

Expected Costs:

$200,000 - $350,000

5.2 Geotechnical

5.2.1 Compile Exposure Data from NEB and ERCB Records

Background

Leir, 2009 provided information related to pipeline exposure of active pipelines. NEB and ERCB records should be examined to provide an expanded database of the rate of exposure for active pipelines and their locations.

Objective and Scope

The objective of the proposed research is to expand the database by compiling an updated list of exposure instances. Using GIS and NEB/ERCB records, correlate exposures with hydrotechnical, geotechnical and wind erosion hazards (this would include third party damages due to reduced depth of cover) where possible.

Expected Result

This can help guide the committee to understand the sites most at risk due to exposure, and where exposure is unlikely.

Project Duration
It is expected that this data review work (depending on the quality and amount of data) could be completed within 3 months.

Types of Organizations that Could Conduct the Research
This type of work may be done internally by NEB or ERCB staff, or alternatively it could be completed by consultants working for these organizations.

Expected Cost of the Research

The proposed research is expected to cost approximately $50,000.

5.2.2 Examine Buoyancy Effects on Pipeline Exposure Rates

Background

A geohazard that is thought to have the potential to significantly increase the rate of exposure post-abandonment is loss of buoyancy control. Liquid pipelines depend on the weight of the product to, in part, control buoyancy. Once the pipeline is abandoned, this additional weight will be removed. For gas pipelines, buoyancy control is installed and maintained during the active phase of the pipeline use. Degradation of these control measures is likely to result in exposure if the initial conditions persist. When considering the need for this study, abandonment measures such as removal of the pipeline, installation of interior weight and puncture of the line should be considered as alternatives.

Objective and Scope
The objective of the proposed research is to study the longevity of different buoyancy control measures.

Expected Result
The results of the research will be to develop a model that could be used to predict the potential for and the timing of exposure of abandoned pipelines due to lack of or loss of buoyancy control.

Project Duration
The project can be completed within six months.

Types of Organizations that Could Conduct the Research
This research could be conducted by a University as part of a multi-year research project or could be completed by a consulting engineering firm specializing in design of buoyancy control

Expected Cost of the Research

The proposed research is expected to cost approximately $75,000 if completed by a consultant.

5.2.3 Examine Frost Heave Effects on Pipeline Exposure Rates

Background

Frost heave also has the potential to result in pipeline exposure. Once the warm product is removed, heave of the pipeline could begin to occur. The rate and importance of this mechanism is thought to depend on soil type and available moisture. No information was encountered in the literature pertaining to this geohazard and its ability to expose a pipeline once abandoned. The literature on performance of culverts could be used as a proxy but also studies could be completed on active pipelines with product near ambient temperatures or suspended pipelines. The studies could take three forms; laboratory testing of soils for frost heave properties, field measurement of heave rates in a single winter and across multiple seasons, and examination of the long term performance of pipelines that are suspended or operating at ambient temperatures.

Objective and Scope

The objective of the proposed research is to understand the mechanism of heaving of abandoned pipelines. A laboratory study could be undertaken to examine, under multiple freeze thaw cycles, the interaction of growing ice under the pipeline against resistance forces above the pipeline. This type of work has been conceived many times for cold gas pipelines, but only a limited amount of information is in the public domain, and testing of the abandonment case was not found in the literature.

The laboratory scale work should be compared to results of field studies of pipelines with product at ambient temperatures or for suspended pipelines. The field scale study would be used to determine the effect of frost on long segments of pipe, versus local frost heave effects that could be determined in the laboratory. The study should include installation of markers on the pipeline and a regular program of surveying the markers. Survey stations should be set-up in a number of different terrains and soil moisture conditions. Thermistors should be installed to monitor the development of the frost front at these stations.

An examination of pipelines operating for a long period at ambient temperatures or where operations have been suspended, should offer a good perspective on the performance of abandoned pipelines.

Expected Result

The laboratory results of the research will be to develop a numerical model to determine the effects of different soil types and moisture conditions on the potential for an abandoned pipeline to become jacked out of the ground by frost action. The result of this lab study would not be definitive, but give general guidance.
The field study of suspended pipelines or ambient temperature product pipeline would provide real scale information related to local frost heave effects on a long section of pipeline.

Project Duration
The project would have to be completed as part of a multi-year effort.

Types of Organizations that Could Conduct the Research
This research could be conducted by a University as part of a multi-year research project or a multi-year effort of pipeline examination and surveys.

Expected Cost of the Research
The proposed research is expected to cost approximately $50,000 per year.

5.2.4 Evaluate Success of Previous Pipeline Abandonment Programs

Background
Pipelines have previously been abandoned in Alberta and other jurisdictions. A review of the approved plans could be conducted to gain a general understanding of the approaches taken. Then, if site visits were conducted to determine the effectiveness of activities, valuable information could be obtained on post-abandonment conditions and performance of various abandonment procedures.

Objective and Scope
The objective of the proposed research is to compile "real time" information with respect to actual procedures used for pipeline abandonment. The scope of the project could cover any abandoned pipelines under NEB or ERCB jurisdiction. A report could be assembled detailing the approaches taken for each site and could include the study of the current ground surface effect of pipelines that are abandoned in place; the study of the current ground surface effects of pipelines that have been removed; and the selection of segments of pipelines that have been abandoned in place, remove them, and observe ground surface changes.

Expected Result
The results of the research will provide a better understanding of the effects of actual abandonment procedures.

Project Duration
The project could be conducted over a number of years, but in each year will only require about 1 month of effort and result in a summary report of observations.

Types of Organizations that Could Conduct the Research
This research could be conducted by a consultant or pipeline operating company.

Expected Cost of the Research

The proposed research is expected to cost approximately $100,000 to initially set up the monitoring stations, and then approximately $25,000 for each year the project is run. It is also assumed that $100,000 would be spent during the fifth year to assess the data collected over each five year cycle.

5.2.5 Collapse of soil under different void sizes, soil types and depth of cover

Background

The mechanism of soil collapse could be studied in three ways;

- examine already pulled pipelines to determine actual collapse and magnitude of the resulting surface effect,
- create voids in soil and accelerate the collapse (this study should examine different pipe sizes, soil types, depths of burial and moisture conditions), and
- Complete model studies using centrifuges.

Objective and Scope

The first item could be part of the study of existing abandoned pipelines, and involve setting up survey points for multiple year studies to examine the eventual collapse of the soil into the void.

The second study could be to set up a test area with a known soil type and moisture, install a pipeline and compact the soil, later remove the pipe and monitor the collapse depth and timing. Loading by different types of equipment could also be examined in this experimental set-up.

The third suggestion is very similar to that of the second, except that with the use of a centrifuge would allow control of the soil used, pipeline diameters and depth of cover. The tests are conducted on a small scale basis and the centrifuge is used to determine the long term effect.

Expected Result

The results of the research will be to develop a model to determine the effects of different soil types and moisture conditions on the potential for soil collapse once a pipeline is pulled out or fails due to corrosion.

Project Duration

The project could be conducted over a number of years.

Types of Organizations that Could Conduct the Research

This would be best undertaken as a university research project or it could be undertaken by a consultant and a commercial testing program at a university centrifuge.

Expected Cost of the Research

The proposed research is expected to cost approximately $200,000 to $300,000

5.3 Engineering

5.3.1 Validation of Culvert Failure Model for Abandoned Pipelines

Background

The California State Department of Transportation has developed a model for culvert failure from corrosion, which is based on field data for the time to perforation of culverts in various soils in California. The model is very simplistic, incorporating soil pH and resistivity, but is reasonable based on extensive research on the topic over the past century. However, the model has not been validated for thicker structures, such as underground pipelines. Estimates of penetration depth versus time for pipelines are needed, for incorporation in plastic instability models, in order to determine the time of collapse for these structures.

Objective and Scope

The objective of the proposed research is to validate the Culvert Failure Model for the thicker shell walls associated with abandoned pipelines. The scope of work will be to analyze the extensive underground corrosion data available in the literature and use relevant data to optimize the Culvert Failure Model for general corrosion of the thicker pipeline steels. This model could then be incorporated with an actual collapse model to predict the time to collapse as a function of soil properties and pipeline dimensions.

Expected Result

The results of the research will be a validated prediction model for penetration versus time of abandoned pipelines, as a function of soil properties.

Project Duration

The project can be completed within six months.

Types of Organizations that Could Conduct the Research

This research could be conducted by contract research organizations, government laboratories, or universities with extensive experience in underground corrosion of corrodible structures.

Expected Cost of the Research

The proposed research is expected to cost approximately $40,000.

5.3.2 Structural Integrity

Background

API 579-1/ASME FFS-1 provides methods for assessing the fitness for service of pipe with general or local metal loss and external pressure loading that could be applied to abandoned pipelines with external pressure loading from soil.

Objective and Scope

The methods in API 579-1/ASME FFS-1 may not be directly applicable to pipeline abandonment as written because they were developed for application to pressure vessels and piping in operating facilities. The review should include evaluating whether the fitness-for-service assessment procedures can be tailored directly to pipeline abandonment issues.

Expected Result

The research would determine the extent to which they can be applied to abandoned pipelines. A detailed review and evaluation of these methods is needed to assess their applicability to pipeline abandonment issues.

Project Duration

The project could be completed within two months.

Types of Organizations that Could Conduct the Research

This research could be conducted by contract research organizations with professional engineers familiar with API 579-1/ASME FFS-1 and pipeline fitness for service issues.

Expected Cost of the Research

The proposed research is expected to cost approximately $30,000.

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APPENDIX A - REVIEW OF RELEVANT PIPELINE CODES

A1. INTRODUCTION

In this Appendix, DNV has reviewed the findings of relevant standards from Canada, the USA, the United Kingdom, Australia, and Argentina. The actual requirements of the different standards reviewed are quoted directly.

A2. Canadian Standard CSA Z662-07 Oil and Gas Pipeline Systems

Pipeline abandonment is considered in Clause 10.17 of the above standard. The guidance provided (as with all standards reviewed) is highly generic.

10.17 Abandonment of piping

10.17.1
The decision to abandon a section of piping, in place or through removal, shall be made on the basis of an assessment that includes consideration of current and future land use and the potential for safety hazards and environmental damage to be created by ground subsidence, soil contamination, groundwater contamination, erosion, and the creation of water conduits.

10.17.2
Piping that is abandoned in place shall be:

(a) Emptied of service fluids;

(b) Purged or appropriately cleaned or both;

(c) Physically separated from any in-service piping; and

(d) Capped, plugged, or otherwise effectively sealed.

10.17.3
Records shall be maintained of all piping that is abandoned in place. Such records shall include locations and lengths for each pipe diameter and where practical, burial depth.

Note: Operating companies should consider maintaining all pertinent records related to the abandoned piping.

A3. Pipeline Transportation Systems for Liquid Hydrocarbons and Other Liquids, American Society of Mechanical Engineers, ASME B31.4-2006

Pipeline abandonment is considered within section 457 of the code as follows:

457 ABANDONING A PIPING SYSTEM

In the event of abandoning a piping system, it is required that:
(a) Facilities to be abandoned in place shall be disconnected from all sources of the transported liquid, such as other pipelines, meter stations, control lines, and other appurtenances
(b) Facilities to be abandoned in place shall be purged of the transported liquid and vapor with an inert material and the ends sealed".

The stipulations are less than those of CSA Z662-07; little consideration is given to environmental protection, and the keeping of records after abandonment is not mentioned.

A4. Gas Transmission and Distribution Piping Systems, American Society of Mechanical Engineers, ASME B31.8-2006

Pipeline abandonment is considered within section 851 of the code as follows:

851.8 Abandoning of Transmission Facilities

Each operating company shall have a plan in its operating and maintenance procedures for abandoning transmission facilities. The plan shall include the following provisions:

(a) Facilities to be abandoned shall be disconnected from all sources and supplies of gas such as other pipelines, mains, crossover piping, meter stations, control lines, and other appurtenances.

(b) Facilities to be abandoned in place shall be purged of gas with an inert material and the ends shall be sealed, except that:

(c) After precautions are taken to determine that no liquid hydrocarbons remain in the facilities to be abandoned, then such facilities may be purged with air. If the facilities are purged with air, then precautions must be taken to determine that a combustible mixture is not present after purging. (See para. 841.275.)

A5. Steel Pipelines and Associated Installations for High Pressure Gas Transmission, Institution of Gas Engineers and Managers, IGEM/TD/1/Ed. 5, 2010 (U.K. Standard)

Pipeline abandonment, or permanent de-commissioning as per the term within the code, is considered within section 12.9.6:

12.9.6 Permanent de-commissioning of pipelines, sections of pipelines and associated installations

12.9.6.1 General

A pipeline, pipeline section or associated installation that is no longer to be used for the conveyance of gas shall be taken out of service, with all hazardous fluids removed and the following options considered:

- Use the asset for another purpose or
- Remove the assets or
- Leave the asset in-situ, but rendered permanently safe.

Note: This may involve removing components, for example valves, and capping open ends so as to leave all sections gas tight.

The following factors shall be taken into account when deciding on the most appropriate option:

- Public safety
- Environmental protection
- Future land use
- Legal duties and residual liabilities
- Practical difficulties and financial considerations
- Maintenance requirements, for example to prevent corrosion of the pipeline leading to pipe wall collapse or becoming a channel for the conveyance of water or gases.

12.9.6.2 For assets left in-situ, consideration shall be given to residual liabilities with the owner or operator of the assets, which may remain in perpetuity.
Note: There may be a continuing duty to monitor the condition of the pipeline and a requirement for maintenance or remedial action, for example to ensure that the pipeline route remains safe and without danger as a result of decommissioning.

12.9.6.3 Taking an asset out of service
The following steps shall be taken when taking an asset out of service:

- Consider dismantling and removal – recommended for all above ground sections but economic considerations may limit this option to short sections of buried pipeline.
- Clear and purge the pipeline of any flammable gases, vapours, or residues
- Physically separate from other parts of the system and isolate from all possible sources of gas.
- If appropriate, fill remaining pipeline sections with non hazardous material, for example by grouting, especially large diameter pipelines at road and rail crossings or at other locations sensitive to subsidence.
  Note: Practical and economic considerations may limit this to short sections of buried pipeline.
- Where it is not practicable to fill a large diameter pipeline section with grout, charge with an inert gas and seal permanently the vent and fill points. Leakage tests should be carried out and pressures checked periodically and re-charged as necessary.

12.9.6.4 Identification of permanently de-commissioned buried pipelines left in-situ

The pipeline or pipeline sections shall be identified by suitable markers.

12.9.6.5 Records of permanently de-commissioned assets left in-situ

Records of permanently de-commissioned assets left in-situ shall be maintained.

A6. Code of Practice for Pipelines, British Standards Published Document (PD) 8010-2:2004,

Part 1: Steel Pipelines on Land

Pipeline abandonment is considered within Section 14 of the code:

14.1 Arrangements for Abandonment

NOTE Attention is drawn to the Pipe-lines Act 1962(11), Regulation 25 in respect of pipeline abandonment, and to the Pipelines Safety Regulations 1996 (12) in respect of general duties to preserve safety throughout the lifetime of the pipeline (including abandonment).

Pipeline systems planned to be abandoned should be decommissioned in accordance with 13.2.4 and disconnected from other parts of the pipeline system remaining in service.

A pipeline should be deemed to be disused when it has been abandoned or when the owners cease to inspect it regularly and are no longer prepared to maintain it in an operable condition.

When the owners are no longer prepared to maintain a disused pipeline in an operable condition they should take precautions to prevent the pipeline from becoming a source of danger or nuisance or having an undesirable effect on any watercourses.

Before being abandoned, the pipeline should be completely disconnected at both ends and if necessary divided into sections. All open ends should be capped and sealed. In certain areas, e.g. those subject to subsidence or where heavy external loads can occur, it can be necessary to close the pipeline at both ends and to fill the abandoned line with a suitable filler.

Where an abandoned pipeline cannot be made safe by this method, it should be removed. In all cases where the fluid conveyed is deemed to be an environmental or safety hazard, or could become so after contact with the soil, the fluid should be completely removed from the pipeline.

The pipeline section being abandoned should always be emptied and then cleaned to ensure that no toxic material remains within the pipe.

All above-ground sections of the pipeline system should be removed to not less than 900 mm (36 in) below ground level. Backfilling and land reinstatement should be carried out in accordance with 10.12.14 and 10.12.15.

14.2 Records

A record should be kept by the owners of a pipeline to indicate that they have taken the necessary precautions. A record plan showing the size and depth of the pipeline and its location related to the surface features should also be prepared and a copy given to the owners and occupiers of the land concerned.

A7. Petroleum and Natural Gas Industries - Pipeline Transportation Systems, ISO 13623

13.5 Pipeline systems planned to be abandoned shall be decommissioned in accordance with 13.2.4 and disconnected from other parts of the pipeline system remaining in service.

Abandoned pipeline sections shall be left in a safe condition.

13.2.4 Consideration should be given to decommission pipelines planned to be out of service for an extended period. The removal of fluids shall be in accordance with 13.3.7.

Decommissioned pipelines, except when abandoned, shall be maintained and cathodically protected.

13.3.7.3 Venting and flaring

Hazards and constraints which should be considered when planning to vent or flare are:

- Asphyxiating effects of vented gases;
- Ignition of gases by stray currents, static electricity or other potential ignition sources;
- Noise level limits;
- Hazard to aircraft movements, particularly helicopters in the vicinity of offshore installations and terminals;
- Hydrate formation;
- Valve freezing;
- Embrittlement effects on steel pipework.

13.3.7.4 Draining

Liquids may be pumped, or pigged, out of a pipeline using water or an inert gas. Hazards and constraints which should be considered when planning to drain include:

- Asphyxiating effects of inert gases;
- Protection of reception facilities from overpressurization;
- Drainage of valve cavities, “dead legs”, etc.;
- Disposal of pipeline fluids and contaminated water;
- Buoyancy effects if gas is used to displace liquids;

- Compression effects leading to ignition of fluid vapour;
- Combustibility of fluids at increased pressures;
- Accidental launch of stuck pigs by stored energy when driven by inert gas.

13.3.7.5 Purging

Hazards and constraints which should be considered when preparing for purging include:

- Asphyxiating effects of purge gases;
- Minimizing the volume of flammable or toxic fluids released to the environment;
- Combustion, product contamination or corrosive conditions when reintroducing fluids.

A8. Pipelines – Gas and Liquid Petroleum. Part 3: Operations and Maintenance, Australian Standard AS 2885.3-2001

8.10 ABANDONING A PIPELINE

8.10.1 General

When a pipeline is to be abandoned, an abandonment plan, including an environmental rehabilitation plan, shall be compiled and approved. The sequence of decision making required to develop and implement the plan should be in accordance with Figure 8.10.1. When a pipeline is abandoned, it shall be disconnected from all sources of hydrocarbons that may be present in other pipelines, processing plant, meter stations, control lines and other appurtenances, and shall be purged of all hydrocarbons and vapour with a nonflammable fluid. Disposal of the purging fluid shall meet all relevant environmental and safety requirements.

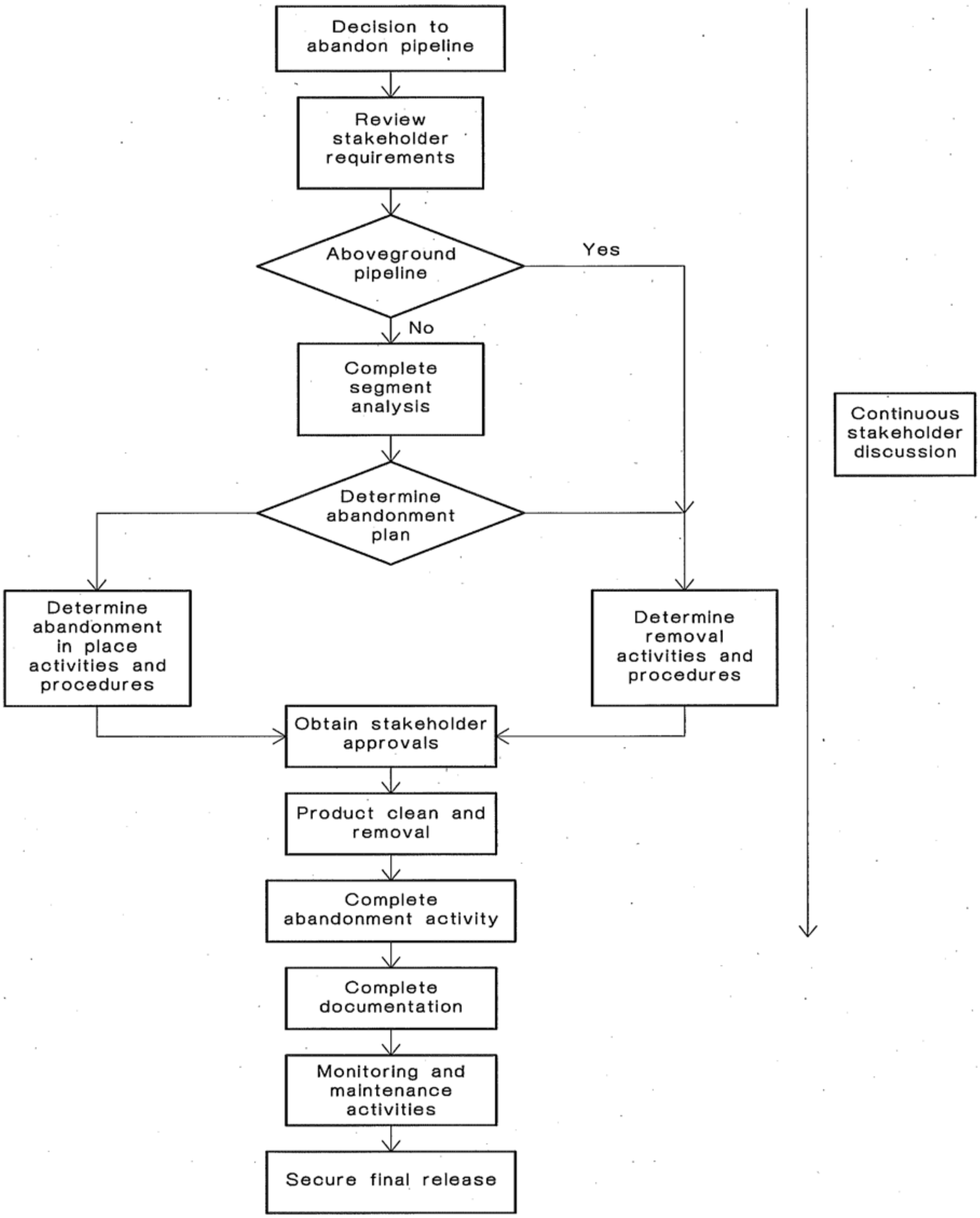

FIGURE 8.10.1 PIPELINE ABANDONMENT FLOW CHART

8.10.2 Abandonment in place

When abandonment in place is approved, the pipeline section shall be abandoned in such a way to ensure that ground subsidence and the risk of contamination of the soil or ground water are minimized.

Where cathodic protection is applied, to prevent the eventual collapse of the pipeline, the responsibility for maintenance of the system shall remain with the pipeline operator and appropriate records shall be kept.

NOTE: Consideration should be given to filling the abandoned pipeline with an inert substance.

8.10.3 Abandonment by removal

When abandonment by removal is approved, the removal of the pipeline section shall meet all relevant safety, and environmental requirements. The requirements for pipeline removal shall be considered as similar to pipeline construction, and shall comply with the relevant requirements of Clause 9.4.3 and AS 2885.1.

8.11 ABANDONMENT OF ABOVE-GROUND PIPELINES

Above-ground pipelines shall be abandoned by removal of the pipeline.

8.12 ADDITIONAL REQUIREMENTS FOR ABANDONMENT

When a pipeline is abandoned, the following additional requirements shall be completed:

(a) The cutting of all buried pipelines at a minimum of 750 mm below natural surface or at the pipeline depth, whichever is the lesser.

(b) The removal of all buildings, fences and equipment.

(c) The removal of all signage associated with the pipeline on completion of the post abandonment maintenance period.

(d) Except where cathodic protection is required in accordance with Clause 8.10.2, the cathodic protection system including buried cables, impressed current units, power lines, solar arrays and batteries are to be removed. Anode and earthing beds are to be disconnected at 600 mm below the natural surface level.

(e) All interference mitigation bonds with third party structures to be removed, that is the pipeline has to be mechanically and electrically disconnected from all other structures.

(f) Obtaining landowner releases for the completed abandonment.

(g) The relinquishing of the easement where no future or continuing use of the easement is proposed.

8.13 ABANDONMENT RECORDS

Where abandonment in place is approved, on completion of the abandonment of the pipeline section in situ, as executed drawings, complying with AS 1100.401, identifying and locating sections of the abandoned pipeline, shall be prepared as part of the relinquishment procedure.

These records shall be made publicly available to prevent possible mistakes in identifying an abandoned pipeline as an operational pipeline.
Records of approved changes of operating conditions, all engineering investigations and work carried out in connection with any change in the operating conditions shall be maintained until the pipeline is abandoned or removed.

A9. Normas Argentinas Mínimas De Seguridad Para El Transporte y Distribución de Gas Natural y Otros Gases Por Cañerías, ENARGAS (1993)

This code (in Spanish) has been reviewed but no reference to pipeline abandonment was found. DNV also has a draft copy of an Argentine code for transporting liquid hydrocarbons, but again no reference was found in relation to pipeline abandonment.

APPENDIX B – ALTERNATIVE RETIREMENT OPTION MATRICES

Retirement Option Matrix
From NEB document A1S0C1 Revisions to Preliminary Base Case Assumptions 4 March 2010

Physical Assumption by Land Use and Facility For the Purpose of Estimating Preliminary Cost Estimates					
Land Use		**Pipeline Diameter**			**Above-Ground Facilities**
		2" to 12" 60.3 to 323.9mm	14" to 24" 355.6 to 610 mm	>26" >660 mm	
Agri-cultural	Cultivated	A: 80% (R: 20%)	A: 80% (R: 20%)	A: 80% (R: 20%)	R
	Cultivated with special features	R	R	R	R
	Non Cultivated	A: 80% (R: 20%)	A: 80% (R: 20%)	A: 80% (R: 20%)	R
Non-Agri-cultural	Existing Developed Lands	A	A	A	R
	Prospective future development	R	R	R	R
	No future development Anticipated (e.g. forest)	A: 80% (R: 20%)	A: 80% (R: 20%)	A: 80% (R: 20%)	R
Other	Environmentally Sensitive Areas	A	A	A	R
	Roads & Railways	A+	A+	A+	R
	Water Crossings	A	A	A	R
	Other Crossings (Utilities)	A	A+	A+	R

Legend: A = Abandon in place,
A+ = Abandon in place with special treatment (e.g. fill with granular material),
R = Removal

Retirement Option Matrix
From CEPA Pipeline Abandonment Options, 2007

Land Use		**Pipeline Diameter**		
		2" to 12" 60.3 to 323.9mm	14" to 24" 355.6 to 610 mm	>26" >660 mm
Agricultural	**Cultivated**	A	A	A
	Cultivated with special features (depth of cover considerations)	R	R	R
	Non Cultivated (Native Prairie, Rangeland, Pasture)	A	A	A
Non-Agricultural	**Existing Developed Lands** (Commercial, Industrial, Residential)	A	A	A
	Prospective future development (Commercial, Industrial, Residential)	R	R	R
	No future development anticipated (e.g. Forest areas)	A	A	A
Other Areas	**Environmentally Sensitive Areas**	A	A	A
	Roads & Railways	A+	A+	A+
	Water Crossings	A	A	A
	Other Crossings (Utilities)	A	A+	A+

Each box in the matrix represents the primary option for pipeline abandonment for each of the land use categories. It is recognized that there will always be a certain amount of pipe that will be removed or abandoned in place for each of the categories based on site specific assessments, but the primary option is the one listed in the matrix. As well, it is recognized that further development is needed to further refine land use categories. This development will occur as part of the development of the risk based site specific assessment process.

The three recommended options available in the matrix are described below.

Primary Pipeline Abandonment Options

Abandonment Option	Description
A	pipeline is abandoned in place
A$^+$	pipeline is abandoned in place with special treatment to prevent potential ground subsidence (e.g., fill pipe with concrete)
R	pipeline is removed

At the initial stages of any pipeline abandonment project, site specific assessments will be necessary and will probably determine that a combination of abandonment options be performed for the various land use categories. In doing so, pipeline companies may determine a percentage split between the primary option in the matrix and any potential secondary option. For example, the matrix recommends that all diameter ranges of pipelines be abandoned in place for a cultivated land use category. However, when the time arrives to initiate an actual abandonment project for this land use category, there is a reasonable likelihood that a small amount of pipe will require removal or abandon with special treatment after the completion of site specific assessments. A similar approach can be applied for the other land use categories.