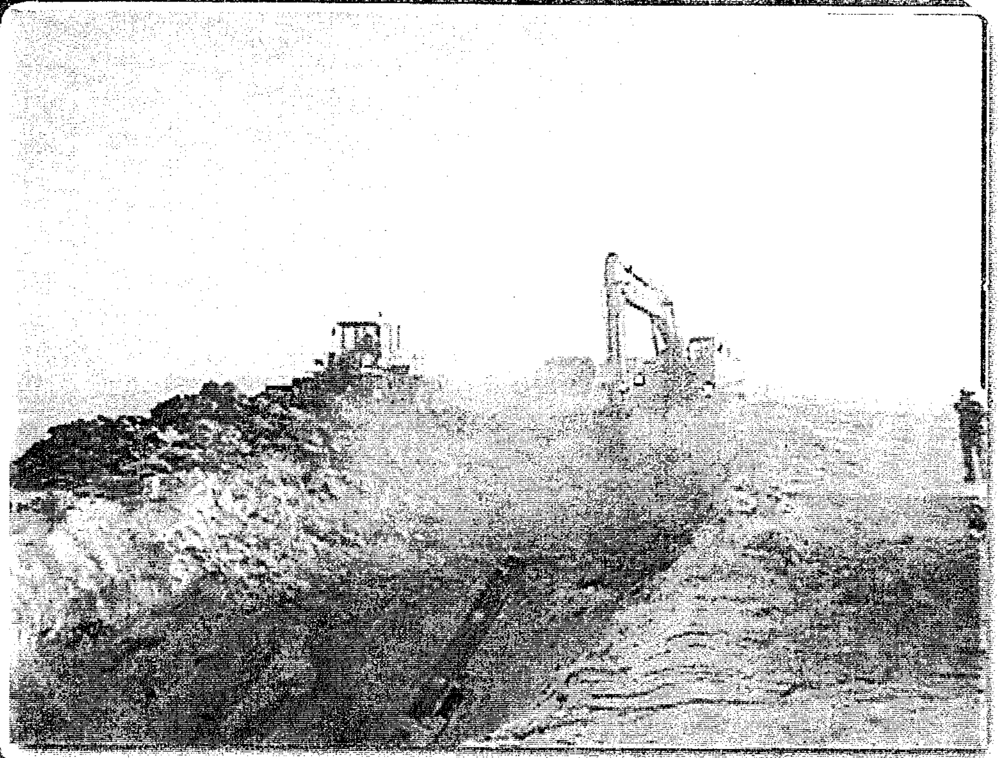


North Slope Buried Pipelines Study

Draft

Submitted to
North Slope Buried Pipeline Task Force

November 26, 2002

Contents

Appendices

List of Tables

List of Figures

North Slope Buried Pipeline Study – Executive Summary

A study has been performed to identify methods for burying pipelines on the North Slope of Alaska. The study was conducted in response to a stipulation in a recent oilfield permit, and to address concerns of some North Slope residents that aboveground pipelines affect human and wildlife use of the land. The study was lead by ConocoPhillips and included a diverse group of stakeholders including regulators, oilfield and pipeline operators, and consulting engineers.

The purpose of this conceptual-level study was to:

- Identify technically feasible options for burying hot oil pipelines in permafrost and develop key technical issues to a conceptual level.
- Identify options that are within or near the reach of current design and construction practice.
- Explore options that are beyond currently feasible design and construction practice, but may be feasible in the future.
- Estimate costs of the most promising options.
- Describe what a buried pipeline project might look like.

The study focused on how a typical "step-out" development (a project outside existing infrastructure) may be developed using buried pipelines. It was assumed that a suite of pipelines similar to recent step-out projects would be required, that the new project would not include on-site processing to remove water or gas, and that the hot fluids would not be chilled before pumping into the pipeline.

The study team developed technically viable conceptual design concepts for burying warm pipelines on the North Slope. Utilizing these concepts however, would result in higher risk, would approximately double the capital cost, and result in higher ongoing operating risk and cost as compared to conventional aboveground pipelines. Solutions relying on unconventional technology such as buried conduits and tunneling are not promising at this time because of technical and cost factors.

Following is a listing of items viewed to be most critical to the better understanding the risks and costs associated with the burial of warm pipelines on the North Slope. Technological advancements would be required in each category to improve the viability of the buried pipeline concept.

- Leak Detection
- Corrosion Protection and Detection
- Pigging Technology
- Surface Revegetation
- Insulation Issues (Performance, Durability, Corrosivity, etc.)
- Constructability
- Cross Drainage
- Access and Spill Response
- O&M Methods

Section 1. Background and Objectives

Aboveground pipelines became the North Slope standard for transporting hot oil and other fluids when the Prudhoe Bay Field was developed in the 1970s. Vertical support members (VSM) installed in the frozen ground supported the pipelines. Placing the pipelines nominally 5 feet above the land surface allowed for air movement beneath the insulated pipelines. The aboveground mode also proved conducive to visual inspection to maintain pipeline safety and integrity, and to monitor potential leaks. People and wildlife crossed the pipelines by passing beneath them, or across animal crossings. Animal crossings are pipeline segments where gravel berms were built over the pipelines, or short segments were buried.

Borealis Pipeline

Phillips Alaska, Inc. (Phillips) led a study on possible alternatives to installing gathering pipelines in the conventional aboveground mode. Results of the study are presented in this report. The objective of the study was to identify a technically feasible option or options for installing hot pipelines below the ground in permafrost (perennially frozen ground) across the North Slope, and to estimate the cost of the most attractive option.

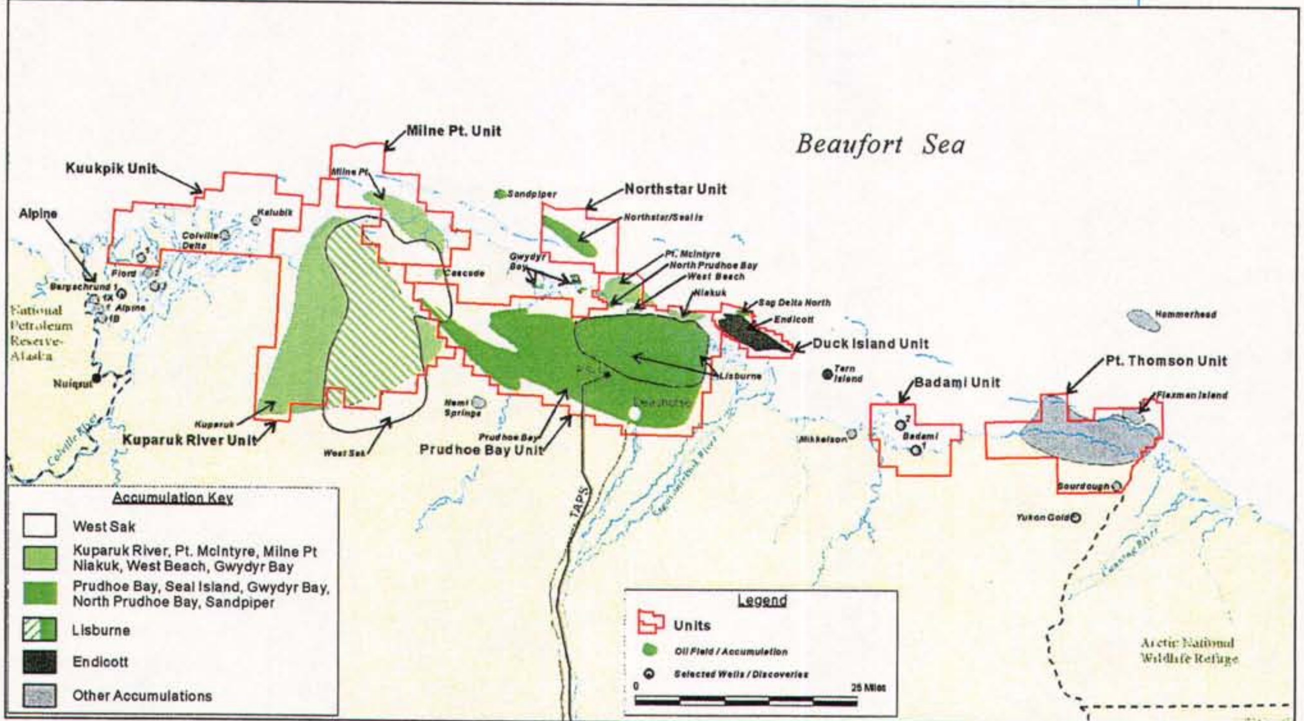
TAPS - Pump Station 4 area

1.1 Reason for Study

Presented in this report are results of the study sponsored by Phillips to determine the best methods of burying hot pipelines required for Alaska North Slope oilfield development. The study was performed to generally address concerns raised by some North Slope residents that conventional aboveground pipelines used for oilfield development may impact wildlife and human movements and behaviors. The study was also to specifically address a stipulation in the North Slope Borough permit that authorized construction of the Meltwater Pipeline in the southwestern portion of the Kuparuk River Unit (KRU) in 2000. This stipulation is:

> *"Phillips Alaska, Inc. shall continue to study alternative pipeline designs that would be safe around human use activities utilizing North Slope Borough Wildlife Department and traditional knowledge, i.e., hunting, cross-country snow machine use; would provide for the unimpeded movement of migratory caribou and other animals; would be environmentally sound; and could be used in areas critical for village use..."*

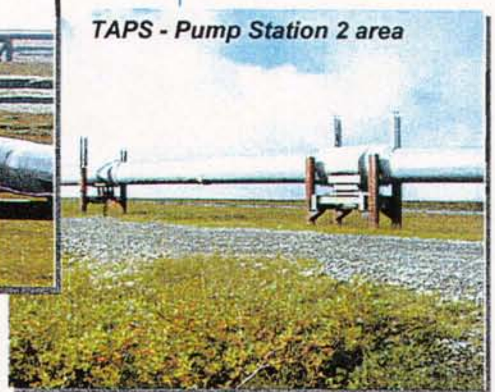
In the past several years, new oilfield developments have expanded beyond the PBU and KRU geographic infrastructure to both the east (Badami) and west (Alpine, Meltwater; map below).



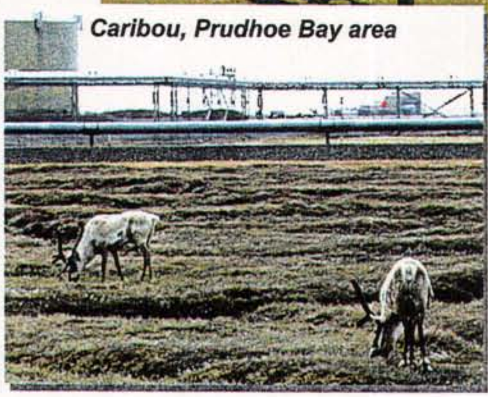
Some Native people on the North Slope perceive that oil field activities, roads and pipelines may delay or deflect the movement of caribou at certain times of the year. Some North Slope residents have suggested that buried pipelines are a possible solution to the potential impacts on caribou migration, subsistence hunting and cultural activities.

Eileen West End (EWE) Pipeline

TAPS - Pump Station 2 area



Caribou, Prudhoe Bay area



The population of Nuiqsut is growing. While this growth occurs, there is a belief by the Kuukpikmuit people that lands traditionally available for subsistence hunting are shrinking because areas where oil field development has occurred are perceived unusable for subsistence activities.

This study has focused on the technical issues related to constructing and operating pipelines below ground on the North Slope. Phillips will continue to perform other scientific studies of wildlife and cultural issues. Phillips' goal is to develop projects in a way that establishes and maintains proper safeguards for the traditional lands used by the people of Nuiqsut to support their subsistence way of life.

1.2 Study Objectives

This study was commissioned to:

- Explore potential methods to safely and reliably design, construct, and operate hot pipelines on the North Slope;
- Determine the best available methods for burying pipelines on the North Slope;
- Outline design, construction, operation, and maintenance issues related to buried pipelines;
- Estimate the cost of the most promising method;
- Consider alternative construction methods that challenge existing technology; and
- Identify shortfalls in technology that require improvement to support the application of the buried pipeline mode.

The Mission Statement for the study was set forth at the study kickoff meeting.

It is the Mission of the North Slope Buried Pipeline Task Force…

…to identify a technically feasible option (or options) to bury oil, water, and gas pipelines to support new oil and gas developments on Alaska's North Slope.

To successfully complete our mission, we must:

- ***Identify and prioritize technical, environmental and permitting challenges;***
- ***Establish engineering and environmental design criteria that assure the challenges are addressed;***
- ***Design and complete engineering, environmental, and permitting tasks necessary to successfully bury pipelines in compliance with the established criteria; and***
- ***Identify operation and maintenance activities that will allow long-term operations of buried pipelines with a high degree of safety.***

1.3 Study Guidelines and Assumptions

...step-out developments

The study team focused on developing methods for burying a suite of buried pipelines typical of recent North Slope "step-out" developments, such as Tarn and Meltwater. This includes a hot, three-phase (produced fluids; oil, water, and gas combined) pipeline of 20-inch-diameter, a hot injection water pipeline, and a miscible injectant pipeline operating at ambient temperature. The step-out developments do not include on-site processing. As a result, a three-phase produced fluids pipeline would be required to bring the fluids to a processing facility. Also, the piped fluids would not be chilled before placing them into the pipeline. Other development scenarios, such as partial or full treatment resulting in single-phase flow, or chilling pipeline contents to decrease thermal effects would result in conclusions and recommendations different than those presented herein. This development scenario was selected because it closely resembled the Meltwater development, which prompted this study.

... hot pipeline burying methods that are within the grasp of existing technology

The study team concentrated on two areas that are described in detail in the following sections. The first was to identify methods for burying hot pipelines using methods that are within the grasp of existing technology. This included consideration of various options of burial, insulation, and refrigeration. Areas where additional work is required to advance existing technology to better fit this purpose were to be identified.

...methods that are not

The second area of consideration is that which includes unconventional methods that are not in the realm of current technology. This includes methods that may be employed in other geographic areas, but are untried on the North Slope, and methods that are unproved throughout the industry. Methods considered under this classification include tunneling and a buried conduit option, similar to a utilidor concept.

Early on in the study process consideration was given to having a facet of this study target guidelines for where buried pipelines would be preferable to above ground lines. Subsequently, it was decided to focus on the engineering, construction, and risk issues related to the burial of warm pipelines, leaving the guidelines for where buried lines were preferable for evaluation by others at a later date. It was felt that better common understandings of the engineering, construction, and risk issues were necessary before any meaningful progress could be made on the guidelines for where buried lines were preferable.

1.4 Study Team

A broad cross section of stakeholders participated in this study. Stakeholders are defined as those who have a strong interest in the decision to develop North Slope petroleum resources, and/or are significantly affected by the developments. Stakeholders include representatives from oil producing companies, state and federal regulatory staff, and representatives from the North Slope Borough. A listing of study participants is presented in Table 1.

1.5 Study/Report Structure

This study was initiated with a kickoff meeting, at which buried pipeline issues were discussed and a general focus was set for the study. Working groups were formed to work specific areas of the study, including Engineering, Design, and Construction; Operations and Maintenance; and Environment and Permitting. Presented in this report are results of the work completed by the Engineering, Design, and Construction; and the Operations and Maintenance work teams.

Environment and permitting issues were considered in as much as they affect design and construction. However, detailed consideration of this topic in and of itself was not in the scope of this study because of the broad scope of technical issues being studied.

Table 1 Buried Pipeline Study Participants

Team Member	Organization	Expertise
Steve Carn	Phillips	Arctic Pipeline Expertise
Mike Fitzpatrick	Baker	Arctic Pipeline Expertise
Bud Alto	Baker	Arctic Pipeline Expertise
Keith Meyer	Baker	Arctic Pipeline Expertise
Tom Lohman	NSB	Land, Native Interests
Al Ott	ADF&G	Fish and Game Issues
Sig Colberg, Robert Watkins	ADEC	Environmental & Oil Spill Prevention Response
Bob Smith	Independent Consultant	Pipeline Research
Alice Bullington	Phillips Permitting	Environmental and Permitting Issues
Warren Christian	HCC	Constr., Maint., & Est.
Willy Friar	BP Projects	North Slope Pipelines
Beez Hazen	NES	Thermal Analysis
Duane Miller	DMA	Geotechnical
Bart Quimby	UAA	Structural Engineering
Dean Carson	Phillips Pipelines	Pipeline Owner
Gary Simmons	Baker	Pipeline Structural
Richard Sloane	Phillips Operations	Operations and Maintenance
Chris Dash	Phillips Corrosion	Corrosion and Maintenance
Paul Fairchild	PAI Exploration	New Projects
Ibrahim Konuk	Canadian Research	Canadian Offshore Expertise
Bill Britt, Tony Braden, Joe Dygas, John Kerrigan	JPO - State	ROW, Pipeline Integrity
Jerry Brossia, Doug Lalla, Don Keyes	JPO - Federal	ROW, Pipeline Integrity
Jon Strawn Sam Saengsudham	USDOT/OPS	Safety/Compliance
Steve Schmitz	DO&G /ADNR	Land Use
Dave Hobbie	USACE	Dredge/Fill/Wetland
Jim Palmatier	Nanuq	Constructor
Roy Varner	NSB	Resident, Permitting
Johnny Aiken	NSB	Resident, Permitting

Section 2. Study Criteria

The objectives of the study, set by the study team during the study kick-off meeting, were to determine how to safely bury hot oil pipelines on the North Slope. Study criteria were established to support achievement of the study objectives. Project criteria are presented graphically in **Figure 1**, and summarized below.

- ***Pipeline thaw settlement*** should be controlled by preventing ice-rich soils beneath the pipeline from thawing.
- ***Ponding*** over the buried pipelines will be prevented by mounding backfill over the buried pipelines following construction. The mounded backfill will move downward and approach the tundra surface elevation as the backfill thaws and settles in subsequent years.
- ***Cross drainage*** must be maintained across the mounded backfill to minimize environmental impacts that may result from causing the adjacent tundra to become wetter or dryer because of the mounded ditchline.
- ***Cross drainage of surface water and shallow groundwater*** will be provided for by grading and providing flow channels where necessary.
- ***Enhanced recovery*** of the disturbance to the native vegetation over the buried pipelines will be via fertilization, plantings, and seeding, as appropriate.
- ***Primary corrosion protection*** will be provided to the pipelines via pipe coating.
- ***Secondary corrosion protection*** will be provided to the pipelines via cathodic protection, or by using construction materials that provide a non-corrosive environment around the pipelines.
- ***Leak detection technology*** will be used to monitor pipeline leaks.
- ***Pipeline upheaval buckling*** will be controlled by burying the pipeline deeply enough to provide sufficient overburden force to keep the pipeline in the ground.
- ***Maintenance and operations*** efficiency, safety, and reliability will be optimized.

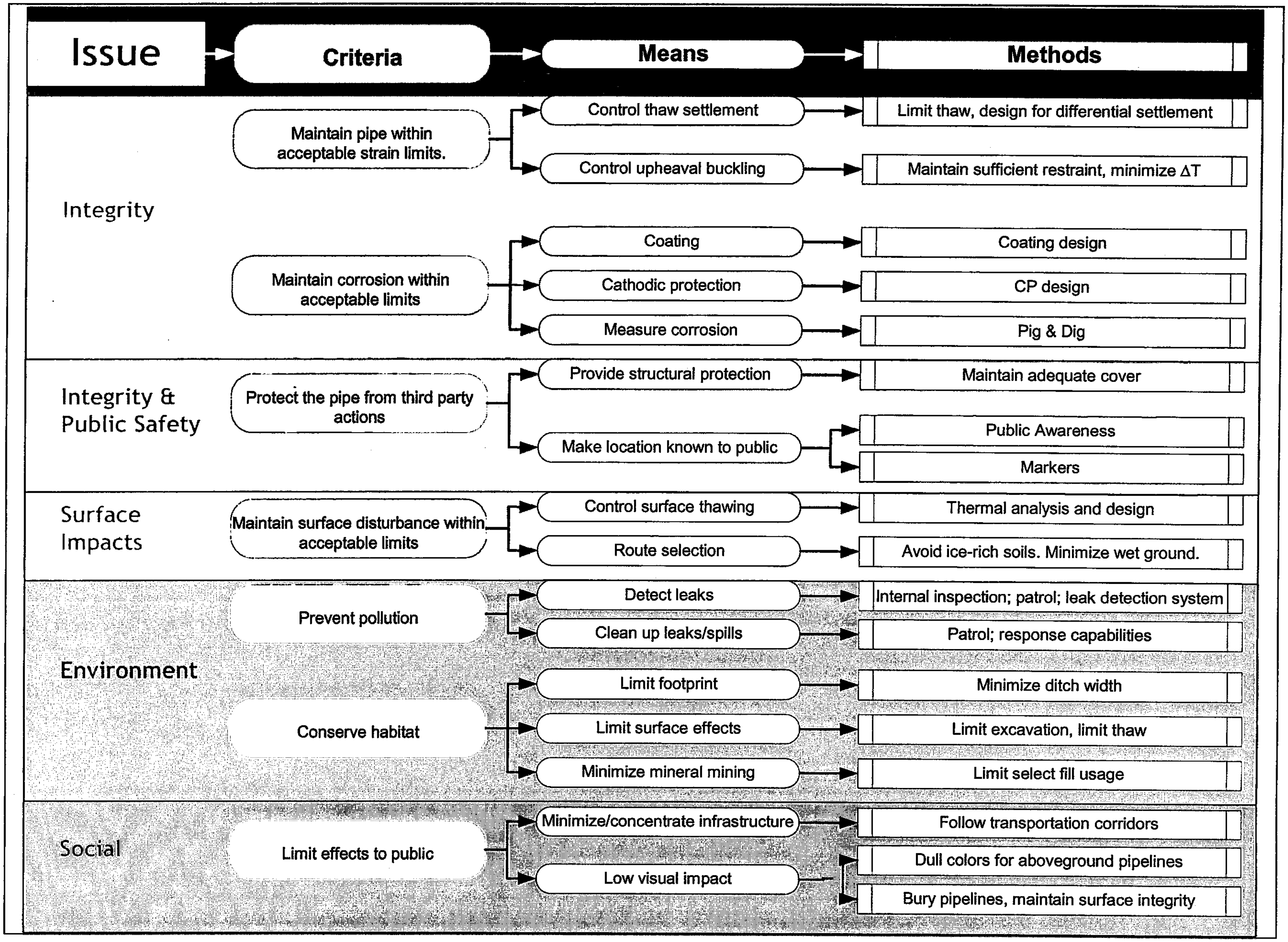


Figure 1 **Buried Pipeline Project Criteria**

Section 3. Critical Environmental Issues

... critical environmental issues that affect the buried pipeline concept...

Engineering and construction issues are the focus of this report. However, many of the key technical issues surrounding the buried pipeline concept are strongly influenced by environmental factors. Some critical environmental issues that affect the buried pipeline concept are discussed below.

3.1 Thermokarst

A thermokarst is a surface depression that forms as the result of thaw settlement or caving of the ground because of melting of ground ice in thaw unstable permafrost. Thermokarst topography can result from features that introduce heat into the ground (such as a buried hot pipeline), or from features that block drainage, that may cause water to pond (such as a road embankment).

Thermokarsting ... adjacent to TAPS Fuel Gas Line Gate Valve 6. (1998)

Thermokarsts commonly impound water, which can lead to further thaw settlement and erosion. Thermokarsts forming over a pipeline can reduce or completely remove cover, possibly exposing the pipe. Thermokarsts off the toe of a road embankment can undermine the embankment and destabilize the road.

3.2 Ditch Subsidence

Ditch subsidence can result from thermokarsting. However, ditch subsidence can also occur even if the pipeline thermal design is adequate, such as when the pipeline is backfilled in the winter, when adequate compaction cannot be achieved. When seasonal thawing occurs during the first few summers after construction, the backfill can thaw and settle. As described above, this is commonly accompanied by surface water ponding, making the problem worse.

Heaving of backfill over pipeline ... Interprovincial Pipe Line System Norman Wells Right-of Way.

3.3 Cross Drainage

Installing a buried pipeline will result in changes to surface topography. From an engineering standpoint, the backfill over the buried pipelines must be slightly mounded to promote surface water drainage away from the ditch line. If ditch subsidence occurs, there will be a trough of surface water over the ditchline. Either a mound or a depression will result in changes to surface water drainage across the ditchline. Altering cross flow will affect the vegetation and habitat on both sides of the ditch.

3.4 Ditch Flow

Surface water ponding

Placing a pipeline through the tundra may provide a pathway for surface and subsurface flow. If ditch subsidence occurs, the surface trough that results may act as a channel for surface water. If imported, clean (not silty) backfill material is used in the ditch, it will be much easier for water to flow through the thawed, sandy material than through the surrounding native, silty soils. This could result in channelized flow in the subsurface.

Ponding over Nuiqsut gas pipeline.

Water migration, either on the surface or in the subsurface is a concern because the migration is accompanied by convective heat transfer, which can result in a dramatic increase in thaw of surrounding soils; and flowing water can cause hydraulic erosion. These factors can compound each other, leading to significant damage to the pipeline right-of-way, impacts to the environment and habitat, a reduction in pipeline safety, and sizeable maintenance costs.

3.5 Unintended Drainage (Draining of Lakes or Wetlands)

Cross- and sub-surface water flow alteration

The cross drainage impacts and ditch flow described in the previous section could result in tapping and draining lakes or wetlands. Even though the North Slope is generally flat, there is enough relief in many areas to result in lakes or marshes that are "perched"; that is, the water body may be higher than the surrounding land. In some cases, lakes or marshes may be a few feet higher than some surrounding terrain. If bisected by a buried pipeline, ditch flow could provide a drainage path that was not previously present. This could drain the lake or marsh.

3.6 Disturbance to Vegetation Over the Ditchline

Once disturbed, most North Slope vegetation is slow to recover. In some cases, disturbance can result in thermal degradation, and recovery of the vegetation types present before the disturbance is not possible in the short term. Vegetation adjacent to the ditch may also be affected if the ditch causes ponding or prevents recharge to the adjacent area.

3.7 Restoration

Restoration will be an important part of any buried pipeline design. However, even though considerable advances have been made in revegetation / restoration technology, restoring the construction right-of-way to preconstruction conditions is very difficult, if not impossible.

Restoration typically involves using fertilizers to encourage the native species disturbed by the construction activity to reinvade the affected area. Native species may also be reintroduced via seeding or by planting cuttings, however this can be difficult on larger projects where substantial areas will be affected, and large quantities of seed and cuttings would be required. Non-native plants are sometimes used if they can be quickly established and provide cover and biomass that can assist native species in re-establishing themselves. Non-native species are generally not preferred as a long-term restoration option.

3.8 Loss of Habitat Over the Pipeline

Vegetation and habitat disturbance

It is quite likely that habitat over the buried pipelines will be lost or significantly altered. Burying pipelines in a ditch may change the plant life that inhabit that strip of land that overlies the pipelines. As described in the previous two subsections, restoration of disturbed ground on the North Slope can be difficult.

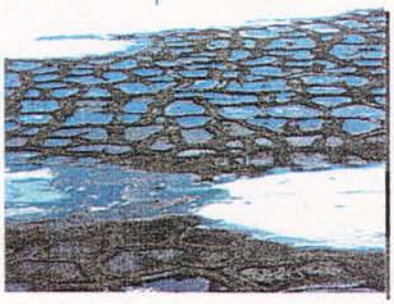
3.9 Damage at River Crossings

Buried pipeline river crossings are particularly sensitive areas. If surface flow patterns are affected at rivers, environmental impacts could be substantial. If surface or subsurface flow is affected (as described in previous sections), the flow of the river can significantly change. If fast-flowing river water flows along the ditchline, erosion of the cover soils is possible, and long segments of the pipeline may be exposed. If the supporting soils are removed, pipeline integrity may be threatened by thermal expansion and hydrodynamic forces.

Undisturbed typical tundra breakup (Colville River Delta. 2002)

3.10 Loss of Habitat (Material Sites)

In addition to loss of habitat resulting from pipeline installation across the tundra, habitat may be lost at mineral material mining sites and spoils disposal sites. Buried pipelines will be backfilled with ditch spoils as much as possible. However, some imported backfill will likely be required, as either bedding, padding, general



Undisturbed typical tundra habitat (Colville River Delta, 2002) backfill, or to replace the volume of ground ice that will be lost upon thawing of the ditch spoils used as backfill. Aboveground pipelines require slurry sand for setting VSMs; however, the quantity of mined soils required for buried pipelines would probably be greater than for aboveground pipelines.

3.11 Impact Avoidance, Minimization, and Mitigation

Environmental impacts of buried pipelines such as those described above can best be avoided, minimized, and mitigated through:

- ***Mode Selection.*** Careful selection of when, where, and under what circumstances to employ the buried pipeline mode;
- ***Careful route selection.*** To minimize length of pipeline in high quality habitat, water bodies and unstable ground, and to maximize the length of pipeline in more stable ground;
- ***Investigations.*** Thorough geotechnical and hydrological investigation of selected routes;
- ***Design.*** Prudent engineering design to account for foreseeable design conditions and potential hazards;
- ***Construction techniques.*** Good construction techniques, including performing work at the proper times of year, winter or summer as appropriate for any given task;
- ***Environmental Restoration and Monitoring.*** Through site restoration and revegetation, and tracking performance of environmental aspects of the operating pipeline;
- ***Civil maintenance.*** Meticulous civil maintenance (especially in the early years after construction); and
- ***Proactive maintenance program.*** A proactive maintenance program throughout the life of the pipelines.

3.12 Impact Repair

Repair methods for the environmental impacts resulting from burying pipelines in North Slope permafrost include:

Thermokarst adjacent to TAPS Fuel Gas Line. (1998)

- ***Thermokarst***. Remove ponded water. Backfill to eliminate future ponding and erosion. Use thermally engineered backfill to ensure freezeback and permafrost maintenance.

Coarse fill material placed over pipe to try to prevent further exposure and to protect pipeline ...Interprovincial Pipe Line System Norman Wells Right-of Way.

- ***Ditch Subsidence.*** Backfill and maintain adequate cover. Use thermally engineered backfill to ensure freezeback and permafrost maintenance.
- ***Drainage Impacts***. Backfill and maintain adequate cover. Sculpt surface to promote drainage away from the ditchline, to match local and regional drainage patterns, and to minimize impacts to crossflow.
- ***River Damage***. River bank erosion can be repaired using proven and conventional techniques, and bank protection can include traditional means such as armor, revetments, guide banks, and spurs. If appropriate and technically feasible, more "environmentally friendly" techniques such as vanes or other structures that promote sediment deposition may be used, or protective vegetation may be used. Past experience with restoring damaged river crossings on the North Slope has shown that these repairs can be very difficult to construct successfully.
- ***Loss of Habitat***. Advances have been made over time in rehabilitating areas where vegetation has been disturbed, such as erosion areas or mine sites. Fertilization and revegetation techniques would be used to restore ditchline, mine sites, or eroded areas.

Section 4. Engineering and Design Considerations

4.1 Thermal Analysis and Design

Likely the most important integrity aspect of successfully designing, constructing, and operating buried pipelines is the ability to bury them in a way that minimizes or eliminates thawing of the ice rich permafrost surrounding the pipelines. The presence of thaw-unstable frozen soils is the primary distinguishing factor between the North Slope and most of the rest of the world, where burial is the standard pipeline mode. Nearly all of the potentially adverse environmental, integrity, and safety impacts that may result from burying hot pipelines on the North Slope result from thawing ice-rich frozen soils.

Nearly all of the potentially adverse environmental, integrity, and safety impacts ...

...result from thawing ice-rich frozen soils.

Mr. Beez Hazen, of Northern Engineering and Scientific, performed thermal analysis using the thermal simulator TQUEST. The process, methods, and configurations used in thermal analysis and conceptual design are briefly discussed in this section. A summary of the key results is also presented herein. A detailed description of the model and of the configurations simulated as part of this study is presented in Appendix A.

4.1.1 Process and Methods

Two-dimensional finite element thermal analysis was performed to simulate the impacts of operating hot pipelines in frozen ground on the North Slope. This method and the specific tool for thermal analysis (TQUEST) are reliable, proven tools, successfully used for many years for this type of work. TQUEST has been validated by comparing predictions made using this method against actual performance data, and is a state-of-the-practice tool for thermal analysis.

4.1.2 Configurations – Roadless Developments

A number of buried pipeline configurations were analyzed as part of this study. Presented in Appendix A is a summary of the more promising results. The most promising configurations include significant thicknesses of insulation, either on the pipelines, lining the ditch, or both. Sketches of these configurations are included in Appendix A.

Recent new step-out developments on the North Slope have included fields connected to the existing infrastructure with new roads (such as Tarn and Meltwater) and fields that are "roadless" and do not include permanent, all-season roads (such as Badami and Alpine). In this section, methods for burying hot pipelines for a new development that does not include a road are described. Later in this report, proposed developments that would include roads are discussed. Most of the issues discussed in this section apply equally to buried pipelines in a development that includes a road, with some minor variations. Issues unique to either road or roadless options are discussed as appropriate.

Configurations considered for burying hot pipelines were selected in consideration of factors that affect the safety, reliability, environmental performance, and regulatory compliance of the proposed developments. These included thermal factors which affect the thawing of the initially frozen soil around the pipes; sufficient overburden to protect the buried lines and provide sufficient vertical restraint; satisfaction of code requirements; prevention of ponding; and minimizing effects to cross drainage of surface waters across the ditchline.

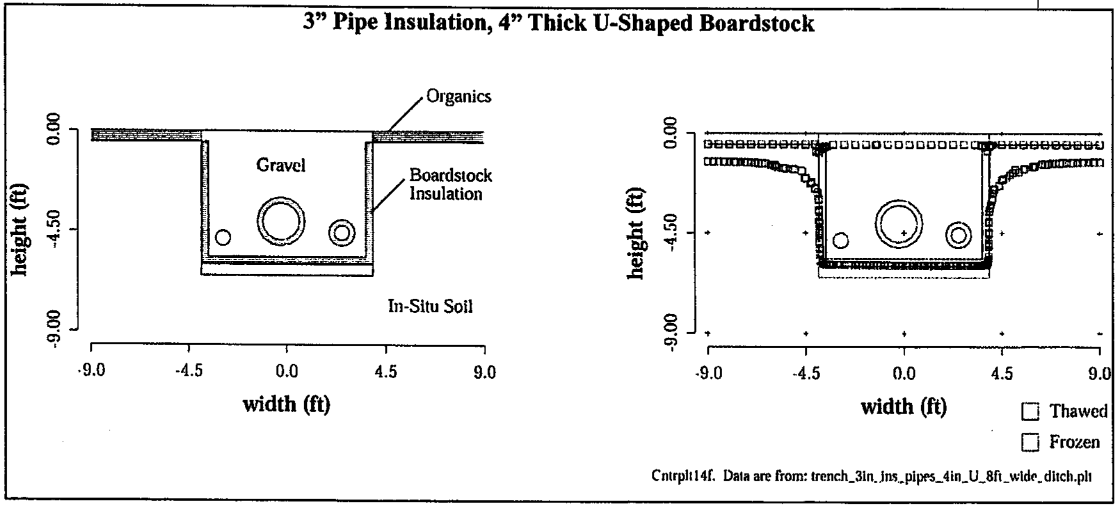
... The most promising buried pipeline configurations

Many configurations were discussed and screened during meetings of the study team. These included several different pipeline layouts and insulation configurations. A team of engineers and constructors further explored these configurations. The most promising configurations are described below.

1. Optimized Pipe Insulation / Boardstock Configuration

The optimized pipe insulation / boardstock configuration consists of using both polyurethane insulation directly attached to the pipelines ("pipe insulation") and boardstock (expanded or extruded polystyrene) insulation to control heat flow from the hot buried lines to the surrounding ice-rich permafrost. This configuration is shown on Figure 2.

Figure 2 Optimized Pipe Insulation / Boardstock Configuration



Source: NES report, Appendix A

Advantages of this Optimized Pipe Insulation / Boardstock configuration include:

- It utilizes two insulation modes, both of which are configured in conventional thicknesses that may be supplied by traditional vendors.
- It includes methods common to North Slope civil construction.

Disadvantages include:

- There is one additional fabrication (or installation) step than if only one type of insulation (either pipe insulation or boardstock) was used.

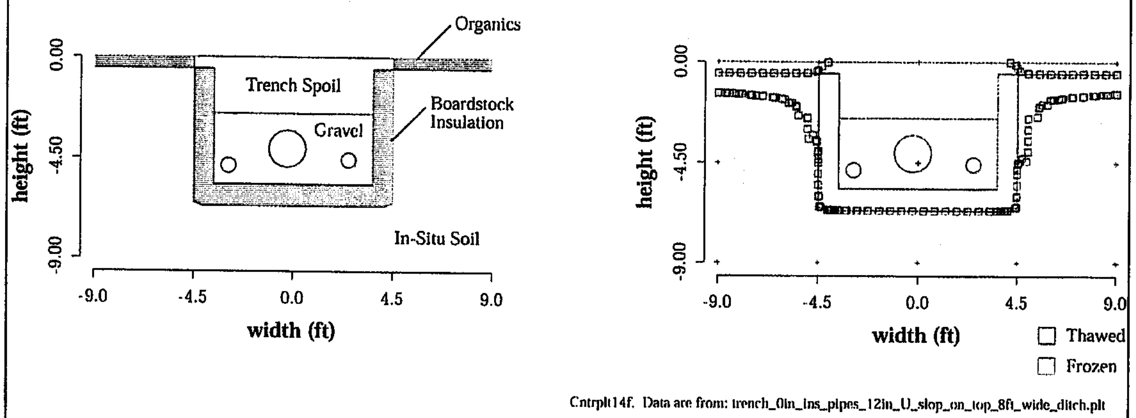
  That is to say, if only pipeline insulation (in a thicker layer) was used, the step of installing the boardstock insulation would not be necessary in the construction sequence. If only boardstock insulation (in a thicker layer) was used, the step of shipping the pipe to the insulation shop for application of the pipe insulation and sheath would not be required, and only the placement of the boardstock insulation would be necessary in the construction sequence.
- Insulation sheath must keep the pipe insulation dry.
- If saturated, the insulating properties of the polyurethane insulation around the pipelines decrease significantly.
- If saturated, the polyurethane insulation around the pipes yields a corrosive environment.
- It is difficult or impossible to provide secondary corrosion protection to insulated pipelines.

2. Expanded Polystyrene Pillow Blocks / Preformed Expanded Polystyrene "U" Configuration (Boardstock)

This configuration (Figure 3) utilizes very thick boardstock insulation to limit thaw of the frozen ground around the buried pipelines, without any insulation installed directly on the pipelines. The insulation is placed beneath the pipelines to limit thaw into the underlying permafrost, as well as along the ditch sidewalls to limit heat flow into the soils beside the ditch. The top of the ditch is not insulated, which allows heat transfer through the thaw-stable backfill overlying the pipe (which thaws completely each summer) into the cooler atmosphere.

Figure 3 **Expanded Polystyrene Pillow Blocks / Preformed Expanded Polystyrene "U" Configuration (Boardstock)**

Uninsulated Pipes, 12" Thick U-Shaped Boardstock Insulation



Source: NES report, Appendix A

Advantages of this configuration include:

- It utilizes only boardstock insulation.
- It is conducive to secondary corrosion protection.

  The pipelines are in direct contact to the soil, so that, when it is thawed, it will conduct electric current and will be capable of providing cathodic protection to the pipelines. Buried pipelines that are covered with pipeline insulation are very difficult to thoroughly cover with cathodic protection because the insulation/sheath impedes flow of electrical current.

- It includes methods common to North Slope civil construction.

Disadvantages of Expanded Polystyrene Pillow Blocks / Preformed Expanded Polystyrene "U" Configuration (Boardstock) include:

- Insulation is most effective when used as close as possible to the heat source. The efficiency of this insulation method may be slightly lower than some other configurations.
- Installation of the boardstock insulation may be difficult under windy North Slope winter conditions.

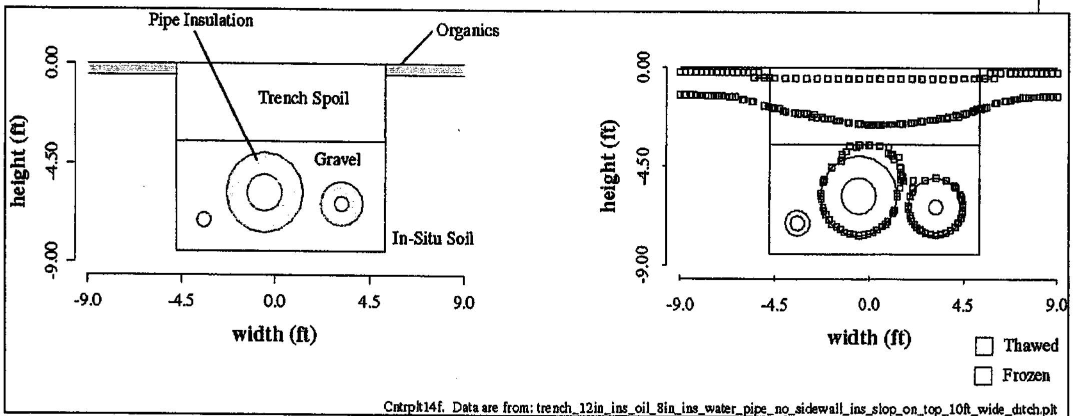
3. Super-Insulated Pipe Configuration

This configuration is shown on Figure 4. The super-insulated pipe configuration features a very thick layer of pipe insulation around the pipelines and no boardstock insulation. This is the most efficient mode of controlling the progression of thaw, and is easier to construct in the field than either of the configurations described previously, because there is no layer of boardstock insulation to install, and the construction sequencing is likely better.

Critical considerations for this option are, as described above, secondary corrosion protection is problematic; and potentially corrosive liquids may be generated in contact with the pipe if the insulation becomes wet.

Figure 4 Super-Insulated Pipe Configuration

12" Pipe Insulation on Oil Line, 8" Pipe Insulation on Water Line



Source: NES report, Appendix A

Advantages of this Super-Insulated Pipe configuration include:

- It simply utilizes pipe insulation, thus removing the North Slope construction step of placing boardstock.
- It includes methods common to North Slope civil construction.

Disadvantages include:

- Insulation sheath must keep the pipe insulation dry.
- If saturated, the insulating properties of the polyurethane insulation around the pipelines decrease significantly.

- If saturated, the polyurethane insulation around the pipes yields a corrosive environment.

- It is difficult or impossible to provide secondary corrosion protection to pipelines insulated in this fashion.

4.1.3 Results of Thermal Analysis

Results of the thermal analyses performed for this study indicate that a number of configurations are theoretically suitable for burying hot pipelines in frozen ground on the North Slope. The key is in placing a sufficient quantity of insulation to keep the long-term thaw bulb within the limits of the pipeline ditch, such that significant thawing of the surrounding ice-rich soils will not occur. Additionally, insulation would likely be placed near the surface to keep the pipeline heat loss from creating an edge effect; that is, the surficial soils adjacent to the ditchline do not thaw, thus avoiding a thaw problem outside the limits of the ditchline.

The key

... sufficient insulation to keep the long-term thaw bulb within the limits of the pipeline ditch...

Issues such as cost, complications resulting from corrosion protection designs, and long-term thermal properties of conventional insulation types were not considered in this analysis.

4.2 Corrosion Resistant Design

Another important integrity consideration is protection from corrosion. Conventional methods for designing, constructing, and operating pipeline corrosion protection measures are somewhat complicated by the North Slope environment. One standard design measure to counter corrosion in buried pipelines is the use of a corrosion allowance. A corrosion allowance is an additional thickness of pipe wall that is over-and-above the thickness required for all other design aspects that is added in case the pipeline corrodes. That is to say, it is thickness that could safely corrode before pressure containment or other design requirements are affected. The corrosion allowance is typically $^1/_{16}$ or $^1/_8$ inch, and is set based on the predicted annual wall loss due to corrosion multiplied by the design life of the pipeline.

...another integrity consideration is corrosion

There are several effective corrosion control approaches for buried pipelines, depending on pipeline and insulation properties. Only carbon steel pipelines were considered in this study, because this is the standard material for North Slope pipelines. Pipelines constructed of other materials (e.g., HDPE, stainless steel) are either technically infeasible, or not cost effective for conventional service.

Corrosion control measures for a pipeline generally include:

- Corrosion allowance (additional wall thickness);
- Primary corrosion protection method (such as pipe coating);
- Secondary corrosion protection method (such as cathodic protection); and
- Inspection program.

4.2.1 Primary Corrosion Protection – Pipeline Coating

High quality external corrosion control coatings are the primary means of corrosion mitigation for buried pipelines. This technique, when properly designed, installed, and maintained, is very effective and likely provides the highest level of protection of any of the corrosion control methods. For this reason, the external coating system must be applied over 100% of the pipeline, must be compatible with the environment to which the coating system will be exposed, and must be durable enough to protect the pipeline for the expected pipeline life.

Fusion bonded epoxy (FBE) is currently the most popular coating system for buried pipelines. Alternative coating systems are available, and would be considered as appropriate. However, FBE is the likely coating system of choice. The FBE coating system is cost effective, has a wide range of service applications, and is durable.

...external pipeline FBE coatings...

FBE is also compatible with several secondary means of corrosion protection, including cathodic protection. FBE may also be applied in the field over short sections (such as at adjacent to field welds) to provide a 100% FBE system. It can also be used in combination with other coating products at field weld joints to provide a continuous coating system. Phillips Specification SPC-MA-NS-80004, External Pipe Coating – Application of Fusion Bonded Epoxy Coating, provides for a sound coating system.

4.2.2 Secondary Corrosion Protection

A secondary corrosion protection system is used to protect a buried pipeline because no primary (coating) corrosion protection system is 100% effective. Coatings always have holidays (small holes or chips in the coating that expose bare metal), which can become larger with time. The exposed metal is then vulnerable to corrosion. A secondary means of corrosion protection is generally used to provide additional protection should the primary system fail.

1. Cathodic Protection

Cathodic protection (CP) is the industry standard secondary means of corrosion mitigation on a buried pipeline. CP is cost effective when applied in addition to a coating system, and is required by federal safety code for transmission lines (49 CFR Part 149). If there are defects in the coating, the CP system will protect the exposed pipe. The CP system must not be "shielded" from the pipeline. Shielding can occur when the insulation and jacketing are between the CP source and the pipe. Additional complications with CP can develop where the pipelines are encased in frozen soil. Frozen soil is not electrically conductive, and thus is not conducive to cathodic protection systems.

Cathodic protection (CP) ….

Testing the effectiveness of the CP system is also required. This is done using test stations and a means of disconnecting the CP to obtain the "instant-off" potentials. A means of adjusting the CP to the pipe is also required. The ability to adjust the CP can range from digging up the pipe to attach new anodes, to changing the rectifier settings of the impressed current CP system.

It is conceivable that cathodic protection may prove infeasible because of environmental conditions, and that no other form of secondary corrosion protection proves feasible. In this case, a risk-based monitoring and maintenance program may be required to provide for safe operations with acceptable risk of corrosion.

Modification of the wet pipe environment …has potential

2. Insulation Modification

Modification of the wet pipe environment is a secondary corrosion protection system that has potential, but still requires field validation. This technique may be applicable when the pipe is directly insulated (cylindrical insulation is bonded directly to the pipe wall). This would be done by formulating the insulation to provide a benign (non-corrosive) environment when wet. The technique currently being investigated is the installation of a phosphate salt into the insulation, to raise the pH of the wet insulation to between 9.0 and 10.5. Carbon steel has a low corrosion rate in this pH range.

Another concept to explore in the future is putting a corrosion inhibitor into the insulation to provide secondary corrosion protection. The objective would be to accept that the pipe insulation might get wet, but take measures to provide that the resulting environment around the pipe would be non-corrosive.

Modifying pipeline insulation to elevate the pH and adding corrosion inhibitor to the insulation are conceptual methods at this time. Many key issues must be worked out prior to application, such as efficacy, affect on thermal performance of the insulation, and potential environmental effects.

4.3 Pipeline Movement

Buried pipelines in permafrost may experience undesired movements during operations. These movements include thaw settlement, frost jacking, and upheaval buckling. Each of these phenomena may result in pipeline integrity concerns, costly and disruptive maintenance actions, and possibly even pipeline leaks. Engineering and design measures to prevent each of these forms of unintended pipeline movements are discussed in detail in the sections below.

4.3.1 Pipeline Strain Limits

Because of the risk of unintended pipeline movements during pipeline operations, it is likely that a limit-state approach would be used. Pipeline strain limits would be set using methods such as have been used for recent pipeline projects that relied on limit-state design. This approach is to use the engineering procedure to determine the amount of strain (deformation) the pipeline can safely withstand in both tension and compression, and then design the pipeline such that that amount of movement (settlement, heave, or upheaval) results in maximum strains that are less than the strain limits.

4.3.2 Pipeline Thaw Settlement

If there is a failure in the thermal design, construction, operations or maintenance, ice rich soils surrounding and below the pipelines may thaw. Upon thawing, the ice rich soils will experience thaw settlement, and fail to support the pipeline causing it to settle or become exposed. The pipeline will assume a settlement configuration dependant on the magnitude of total and differential settlement, the length of the settled span, the stiffness of the pipeline, and the character of the transition zones between the soils that have settled and those that have not.

If the thawing and soil settlement is not extreme, pipeline settlement may be limited, and the resulting pipeline settlement configuration may not cause strains to exceed the strain limits. The magnitude of settlement may be acceptable.

During design, the allowable magnitude of thaw settlement will be set to maintain strains below the allowable strain limits, and threshold levels of settlement will be set. This is generally in the form of allowable curvature of the settled pipeline, to be monitored during operations as described later in this report.

4.3.3 Pipeline Frost Jacking

Although frost heave is normally associated with the design and operation of large gas pipelines operated at cold (below freezing) temperatures, it can also be an important design consideration for pipelines that operate at ambient ground temperatures and pipelines that are dormant (prior to being put in service, or in shutdown mode). A chilled gas pipeline passing through unfrozen soils will cause a zone, or "bulb" of frost to develop with time. For a large diameter cold pipeline, this bulb will continue to grow for many years.

Deep seasonal frost action or transfer of freezing temperatures from frozen areas to thawed pipe segments may act in a similar way on ambient temperature pipelines. The presence of the freeze front (the outer limit of the frozen bulb) establishes temperature and pressure gradients within the adjacent unfrozen soils. These gradients move moisture to the freeze front. Frost heave of a soil mass results from the expansion due to the freezing of the pore water within the frozen bulb, as well as the development of segregated ice lenses due to the freezing of soil water as it arrives at the freeze front. Of the two components, the second, ice lens growth at the freeze front, is the most significant.

In order for frost heave to occur, three conditions must exist concurrently: 1) soil moisture supply; 2) sufficiently cold temperatures to cause freezing of soil moisture; and 3) a frost-susceptible (fine-grained) soil.

Section of exposed pipeline with half steel pipe section and rock over top for protection. ...Interprovincial Pipe Line System Norman Wells Right-of Way.

If drainage is impeded in non-frost-susceptible soils, freezing of the soil moisture may result in slight upward movements due only to volumetric expansion of water. The amount of heave a given soil will generate upon freezing is a function of many factors, including physical soil properties (grain size, soil moisture, and density); thermal gradient at the freeze front (pipe temperature, unfrozen soil temperature); and overburden pressure at the freeze front.

Frost penetration beneath the pipeline and any attendant frost heave will displace the pipeline upward. Uniform displacement of the pipeline upward will not cause adverse effects on the pipeline, but will reduce the depth of cover and may cause erosion by changing surface water drainage patterns.

The type of frost heave that may be detrimental to pipeline integrity is differential frost heave. Differential frost heave may occur at thermal transitions from permafrost to non-permafrost soils, and at changes in soil type where the heave magnitude is substantially different for the different soils. This differential frost heave will displace the pipeline unevenly and may induce strains and associated stresses in the pipeline and beyond design limits.

The impact of the differential movement on the pipe is determined by:

- The magnitude and rate of frost heave;
- The geometry of the initial transition area;
- The uplift resistance provided by soils outside the heaving area;
- The initial thermal gradients between frozen and unfrozen areas;
- The initial stress state within the pipeline;
- The span length over which the differential heave occurs; and
- The strength and stillness of the pipeline.

Pipeline appurtenances, such as valves, may also be affected by frost heave. Valves are potentially sensitive since they are large, critical pipeline structures and may suffer damage if differential frost heave were to occur.

Design measures to account for frost heave are like those described for thaw settlement. The allowable pipe strains are determined, and these are related to allowable differential heave magnitude and pipeline curvature. The pipeline is then designed to comply with these limits, and the pipeline would be monitored for compliance during operations.

There will be locations where frost heave impacts exceed the allowable performance criteria for minimum pipe wall thickness as determined from stress/strain analysis and existing codes. Where this occurs, mitigation measures can be developed to reduce the adverse impact of frost heave on the pipeline. Mitigation techniques may include excavation to relieve the pipe strains and remove frost-susceptible soils, pipe replacement, or other suitable means. Most of the conceivable mitigation techniques would likely be costly.

4.3.4 Pipeline Upheaval Buckling

Some pipelines buried in the arctic and some subsea pipelines have experienced upheaval buckling. "Upheaval buckling" is not the same as the "buckling" that refers to permanent crumpling of the pipeline wall due to high local strains, such as those that result from extreme settlement. Upheaval buckling generally results in movement of a significant length of the pipeline (commonly a few hundred feet), and the movement is generally elastic (the pipeline wall is not permanently wrinkled).

Upheaval buckling of the TAPS Fuel Gas Line. (1998)

Upheaval buckling is lateral deflection (upward movement) of a pipeline segment as a result of longitudinal compression in the pipeline. The compression results from operating the pipeline at temperatures significantly higher than the temperature at which it was installed. This temperature differential causes the pipeline steel to expand; or in other words, the pipeline attempts to grow longer than it was when it was installed.

If the pipeline is adequately restrained, the temperature effect results in compressive forces in the pipeline. If it is not adequately restrained, the compressive forces cause the pipeline to deflect laterally, similar to how a plastic straw bends when the ends are pushed together. The pipeline moves laterally in the direction of least resistance, upward in locations where there is inadequate cover.

The strains in the pipe can become large, and then decrease as the pipeline deflects to relax the longitudinal compression. As the pipeline deflects, axial stresses decrease, and bending stresses increase. It is possible for the pipeline to deflect above the ground surface as a result of upheaval buckling.

In design, upheaval buckling is addressed by providing sufficient cover over the pipeline to prevent the vertical deflections, maintaining the pipelines encased in frozen soils, installing mechanical anchors to restrain the pipeline, or by allowing the pipeline to expand longitudinally. Another approach would be to minimize the construction/operations temperature differential through minimizing the pipeline operating temperature, and/or raising the construction (tie-in) pipeline temperature.

Section 5. Construction Considerations

Buried pipelines on the North Slope will pose a new set of construction challenges. A likely construction sequence is described in this section, including discussion of potential construction problems and approaches to solving those problems. This approach does not represent the only potential construction approach, nor does it necessarily represent the optimum approach. It is intended to identify some of the likely construction practices and challenges for purpose of discussion and to provide a basis for a conceptually representative cost estimate.

Buried pipelines ... a new set of construction challenges

5.1 Excavation

Installation of buried pipelines must minimize any open trench as snow entering a trench packs very hard and is difficult and time consuming to remove. The snow will also commingle with excavation spoils, pipe, and other materials and tools in the work area. Experience indicates that the proper procedure will require preparation and testing of all pipelines and conduits prior to opening a trench for installation. As a trench is opened, the materials are installed in a continuous moving process through completion of the backfill. The production will be tied to the slowest link in the process – most likely the excavation. Excavation will probably be accomplished with a combination of trenchers and continuous mining technology.

The installation of VSMs was a slow expensive process until the development of faster drills and the scheduled separation of drilling from the remaining production tasks. Buried pipelines may also go through a development process until the excavation can outpace the production rate of the pipeline installation process.

...optimization of trench geometry and excavation methods...

The cost of construction may be reduced over time, as design and construction improvements are made. These improvements are likely to be in the form of optimization of the trench geometry and excavation methods, methods for keeping snow from accumulating in the open ditch, techniques for removing snow from the excavation, and in decreasing the number of construction steps required for pipeline construction. Each pass down the line (stringing, welding, excavation, insulation, etc.) is time consuming and requires coordination, while also increasing the risks associated with an open trench. Construction of buried pipelines on the North Slope would likely progress as described below.

5.2 Construction Sequence

Multiple season construction

Buried pipeline construction would likely require multiple seasons. Initial construction would be in winter, with follow-up activities in the following summer and winter seasons.

Construction would begin with laying out the route via surveying and setting points of intersection (PIs) and laying out ice roads, workpad, laydown, and storage areas. "Pioneer" ice roads and pads would be built, using low ground pressure equipment, followed by production and hauling of ice aggregate and additional water placement to complete the ice road and pad construction.

When ice road and pad construction is complete, pipe hauling and stringing would begin. The pipe would be lined-up and welded, then hydrotested (alternatively, the hydrotest could be performed in the summer following construction and some cold-temperature complications may be reduced; however, locating leaks would be more difficult after backfill, and if repairs were necessary, they would be more difficult, disruptive, and costly in the summer). The weld joints would then be coated and any coating defects found by inspection would be repaired. Boardstock insulation, cathodic protection materials, and any other materials required for construction would be staged where required, and readied for installation.

A key installation consideration … is to minimize the wind blowing snow into the open ditch, particularly after the pipelines have been lowered-in…

During ice road and pad construction, surveying would also be performed to set control, stake the ditch limits, and set reference points. When ice works have been completed and sufficient ditch had been staked, and the above construction steps are complete, trenching can begin. As many preparations as possible must be completed before opening any ditch and once the trench is excavated, all other construction steps must be completed as quickly as possible and the trench backfilled as quickly as possible.

Trenching would likely be done with chain-type trenching machines. The chain trenchers would be used to cut 12- to 18-inch wide slots along the edges of the proposed trench, which would be on the order of ten-feet-wide and six-feet-deep. One or two additional slots may be cut in-between the defined ditch limits to isolate "blocks" of soil that could be broken out and removed with backhoes, and set aside for use as backfill.

Reburial of TAPS Fuel Gas Line segment that had experienced upheaval buckling. (1998)

Bedding material would be hauled and placed in the bottom of the ditch and smoothed to form a level base for the boardstock insulation to be placed upon. The thick sheets of boardstock would be placed in the bottom and sides of the ditch, additional bedding sand would then be placed on top of the insulation. Pipelines, conduits, leak detection tube, and the CP anode would be placed on the bedding sand, surveyed, then covered with additional sand for padding. Sand for bedding and padding will be taken from the trench spoils or imported, as appropriate. The remaining spoils, which had previously been worked to break them down into reasonably sized (say 1-foot or less) blocks, would be placed as general backfill. The backfill would be mounded at least two feet higher than the adjacent tundra surface elevation to allow for thaw settlement of the winter-placed, frozen backfill materials. Fine-grained and organic material would be placed as the final course over the backfill to promote revegetation.

Additional construction activities would then be completed, such as installing CP test stations and other appurtenances. The construction spread would be cleaned as well as possible, including scraping the ice roads and pads dirtied by the construction activities, picking up trash and construction materials, and removing staking and ice road delineators, thus completing the initial construction phase.

The next phase of construction would occur in the summer following initial construction. During this phase, the construction zone would be further cleaned of materials that may have been buried by snow the previous winter. The thawing backfill materials would be worked and graded to fill the ditch, mounded to prevent ponding over the ditchline, and to provide local drainage as required. The surface soils would then be fertilized and planted. Planting may include seeding and placing shoots, as appropriate for the location. This work is largely or completely hand work, since the soft ground over the pipelines would not support equipment. Wildlife considerations would also preclude use of equipment during critical (nesting, calving) periods.

Additional earthwork would likely be required in the next winter to place additional fill where depressions exist. The depressions will form where ice and snow were buried during initial construction. The same types of handwork will then be required the following summer, and possibly in later summers after the hot pipelines thaw additional soils. Additional vegetation work (fertilizing and plantings) will also be required where initial efforts failed.

Section 6. Operations and Maintenance Considerations

Transmitting hot fluids through buried pipelines in frozen ground will require operational and maintenance methods different from those used to operate conventional aboveground North Slope pipelines. Presented in this section is a discussion of some methods that would likely be used to operate and maintain buried pipelines. An important part of pipeline operations and maintenance is pipeline and right-of-way surveillance and monitoring. Surveillance and monitoring will be planned and conducted in coordination with pipeline operations. Surveillance and monitoring results will be key inputs used to plan maintenance activities for the pipelines.

for…buried pipelines programmed maintenance would be substantially different…

6.1 Operations and Maintenance Philosophy and Goals

The philosophy for operating and maintaining hot buried pipelines in permafrost is to safely deliver fluids between the production site and the point of delivery with a high degree of safety, reliability, efficiency, and economy. Operations and maintenance goals are to maximize production and safety for the lowest lifecycle cost.

Critical considerations that potentially affect safety, the environment, or pipeline integrity are described below.

6.2 Programmed Maintenance

Programmed maintenance (PM) for buried pipelines would be substantially different from that for aboveground pipelines. More intensive effort will be required for PMs of buried valves, insulation, internal corrosion monitoring coupons, etc. Maintaining these items in the buried mode will require excavation to access the components, or the use of vaults to allow access. Alternatively, pipeline appurtenances could be placed aboveground.

…access…

6.3 Access

Access to buried pipelines in a roadless development scenario will be comparable to access to aboveground pipelines in a roadless scenario. For either type pipeline in a roadless development, access to any point on the pipeline will require use of winter ice roads, helicopters, or low ground pressure vehicles such as Rolligons or sno-cats. However, more equipment would likely be required for most activities on a buried pipeline compared to an aboveground pipeline. For example, a corrosion inspection on a buried pipeline would necessitate use of an excavator and dewatering equipment that would not be required for inspecting an aboveground pipeline.

6.4 Ground Temperature Monitoring and Data Analysis

In addition to standard operations and maintenance monitoring, ground temperature measurements would also likely be made at selected locations during the operations phase to track ground temperatures, evaluate the performance of the thermal design, monitor trends, and possibly detect thaw settlement areas. The measurements would be made using instrumentation installed prior to commissioning, measured at specified frequencies, and trended over time.

...ground temperature measurements

6.5 Corrosion Monitoring and Maintenance

6.5.1 Corrosion Detection

During operations it will be necessary to verify that corrosion protection systems are working properly, and to identify when and where mitigative measures are required to correct deficiencies. For existing aboveground pipelines, corrosion detection is largely accomplished using external devices that move along the top of pipe. These tools search for corrosion using ultrasonic (UT) technology.

...corrosion detection ...

For buried pipelines, corrosion detection will likely be through the use of corrosion detection (CD) pigs, which are internal devices. CD pigs are launched into the pipeline at the point of origin, move through the pipeline with the flowing pipeline fluids, and are removed at the point of termination using a pig receiver. CD pigs use a variety of technologies to detect corrosion, such as magnetic flux leakage (MFL) and UT. Data are retrieved, reduced, and analyzed. If wall thickness anomalies are detected, they are analyzed and graded. If the wall thickness anomalies are severe enough, the pipeline may be excavated at these locations for inspection and if necessary, reconditioning or repair. All pig data would be cataloged in a suitable electronic format (such as a geographic information system, GIS) for analysis and trending.

corrosion detection (CD) pigs

In-line coupons or quills may also be used to investigate the presence of corrosive environments inside the pipeline that may lead to internal corrosion. These methods entail precisely monitoring the rate of metal loss in-stream and using results to optimize use of corrosion inhibitors.

...in-line coupons or quills may also be used.

6.5.2 Corrosion Inspection and Repair

If pipeline corrosion is detected, it must be arrested prior to it becoming an integrity-related issue. Pipeline inspections are made in the winter, unless an emergency condition is identified. Pipeline inspection digs are conducted by determining the precise location of the anomaly from the pig records, field locating the anomaly, then excavating to the anomaly.

Once recovered, the pipeline is carefully cleaned, the wall thickness is directly measured using highly accurate ultrasonic techniques, and the remaining wall strength is calculated. If the remaining strength provided by the reduced wall thickness is still acceptable and the source of wall loss has been arrested, the pipe will likely be cleaned, recoated, and reburied. If the remaining wall thickness is unacceptable, a steel sleeve may be installed on the pipeline to provide required strength before the line is recoated and reburied. Repairs will be catalogued in the pipeline GIS and re-examined in future pig runs. Following the inspection, the pipeline is backfilled and the site restored.

...visual civil surveillance and monitoring

6.6 Surveillance and Monitoring

6.6.1 Civil

Civil surveillance and monitoring for buried hot pipelines will consist of regular passes down the right-of-way to search for conditions that may affect pipeline integrity, land surface disturbances, or pipeline operations. Conditions to search for will include such things as surface expressions of pipeline settlement, frost jacking, or upheaval buckling; thermokarsting; displaced insulation; ponding; impedance of surface drainage; and unsuccessful revegetation.

...FLIR indirect surveillance...

6.6.2 Security

Surveillance and monitoring for security purposes will likely not be significantly different than for aboveground pipelines. Burying pipelines is not expected to result in any condition that would increase the vulnerability from a security standpoint. A buried pipeline may even be less vulnerable because it is less accessible, however security monitoring would probably not decrease.

6.6.3 Oil Spills / Leaks

Surveillance and monitoring for oil spills will be significantly different than for aboveground pipelines. Because the lines are buried, leaks will not be immediately visible. Leak detection is described in detail in the following section; however, oil spill surveillance would likely be required as well, in addition to SCADA-based and direct detection methods.

Oil spill monitoring would likely include frequent visual surveillance, as well as a type of indirect surveillance such as forward-looking infrared (FLIR), which would detect higher ground temperatures resulting from the spilled hot fluids. Use of visual surveillance and FLIR for a buried pipeline would be less effective for a buried pipeline than for an aboveground pipeline because the pipeline itself is not visible, and it would take time for the visual or thermal expression of a leak to be detected at the surface.

6.6.4 Pipeline Position Monitoring

Pipeline position monitoring ...

"curvature pig"

Because of the risk of undesirable pipeline movements (from settlement or heaving), some type of pipeline position monitoring will likely be required. This is most effectively done via pigging, as described above for corrosion monitoring. A "curvature pig" which uses inertial guidance system technology to precisely determine the position and curvature of the pipe, is run in-line. Pipeline centerline location, along with measurement of deformation of the pipe cross section are measured and recorded. Upward or downward movement of the pipeline is thus tracked and trended, and repair activities can be scheduled.

The frequency of the curvature pig runs is determined based on the predicted time to reach objectionable pipe strain. That is to say, the runs would be scheduled such that movements of the pipeline could be remedied prior to reaching a critical state of curvature. Runs would be more frequent (say 6- to 12-month intervals) early in the design life, then less frequent (annually, biannually, or every five years) when the line was older and had a reliable performance record.

Other instrumentation, such as survey monitoring rods, settlement cells, tiltmeters, or other devices may also be installed to give indications of pipeline movement at point locations. The need for other devices would be made on a case-by-case basis, likely in specific areas where pipeline movement had occurred, was suspected, or where conditions conducive to pipeline movement exist.

6.7 Leak Prevention

Buried pipelines generally leak because of external corrosion, leaking fittings, or from external damage (e.g., backhoe strikes). Risk of these types of leaks may be minimized via sound design; skilled construction; and prudent operations, maintenance and monitoring.

6.7.1 Corrosion Leaks

Prevention of corrosion leaks is addressed in the design phase via specifying an appropriate corrosion allowance, proper selection of primary corrosion protection (e.g., coatings), and secondary corrosion protection (e.g., cathodic protection). The corrosion allowance is an additional amount of wall thickness, beyond the wall thickness required for pressure containment and other design conditions, with an appropriate factor of safety. The corrosion allowance then, could be removed by internal or external corrosion without decreasing the safety of the pipeline. Risk of corrosion leaks is further reduced during operations via monitoring, maintenance, and repairs, as described above under Corrosion Monitoring and Maintenance

6.7.2 Leaking Fittings / Valves

Leaks may occur at valves and other fittings if a seal fails. The risk of this occurring is minimized by programmed maintenance activities to inspect and replace seals when necessary. Other causes of leaks (fatigue failure of appurtenances, cracked valve bodies, etc.) may be reduced via programmed inspection, maintenance, and repair.

6.7.3 External Damage

In areas other than the North Slope, the external damage risk is generally greatest from the activities of others. Excavation for other construction activities, for example, is a common cause of pipeline damage and leaks. This is not likely the case for a North Slope buried pipeline since there are comparatively few excavation projects envisioned, the presence of buried cross-country pipelines is likely to be common knowledge to those planning and performing excavations, and the surficial expression of the buried pipelines is likely to be quite evident. Pipeline markers – required by federal pipeline safety code for common carrier pipelines – will further warn third parties of the presence of a buried pipeline.

The greatest risk of external damage to the pipeline likely exists in the pipeline operator's maintenance and repair activities. While excavating the pipeline for monitoring, maintenance, or repair activities, there is a risk of a backhoe strike, dropping equipment or materials on the pipe, or other sort of damage. This risk is minimized by carefully planning all activities near the pipelines, and strictly following procedures designed to safeguard the pipe. Such procedures include precise surveying, probe-and-dig methods, hand excavation of soils near the pipelines, and very close supervision of all field activities.

6.8 Statistical Analysis of Leaks

Comparison of leak rates between classes of pipelines…

… useful for safety performance assessments

A comparison between leak statistics for oil and hazardous liquid transmission pipelines across the United States to leak statistics for gathering pipelines and a handful of transmission lines in the Kuparuk River Unit (KRU) on the North Slope of Alaska is included in this section. The statistics do not include gas pipelines. The evaluation is useful to compare the operational safety performance of the two classes of pipelines in their respective modes.

Each data set allows the calculation of a common metric – Leaks per diameter-inch-mile per year. This normalizes the statistics to account for the average incidence of leaks in liquid pipelines of varying lengths and diameters, and is a unitized measure of the safety performance of the classes of pipelines. However, because of the nature of the data sets (described in the following subsections), the calculation method is different for each data set. The comparison is still valuable because is gives a measure of the safety performance of the two types of pipelines – buried and aboveground. The comparison is valid so long as the difference in the calculation methods (each of which is appropriate for its data set) is understood.

1. Statistics for Buried Pipelines across the United States

Leak and pipeline data used to compile statistics for buried transmission lines are from the United States Department of Transportation, Office of Pipeline Safety (OPS). The OPS receives its authority from the Code of Federal Regulations (CFR) 49, Parts 186-199 to oversee pipeline safety. Pipeline system operators report pipeline operating system data and operating "incidents" (including leaks) to the OPS. Data for oil and hazardous liquid pipelines are tabulated and published in electronic format on the internet. Gas pipeline safety statistics are also published, but were not included in this analysis since our evaluation was focused on liquid lines.

USA Transmission Pipeline Leak Data

The data published by the OPS includes all leaks from regulated systems, including leaks from pipelines, pump stations, and breakout tanks. They are published electronically on the internet, and described as "Hazardous Liquid Accident Data–1986–Present." Another page on the OPS website includes the "Liquid Pipeline Operator Total National Mileage" for the years from 1986 to 2000, from the OPS user fee assessments. These data are specific to hazardous liquids, and do not address gas transmission system incidents. Gas transmission incidents are tracked separately.

USA Data Reduction

Data from 1986 through 2000 were available from OPS and these data were compiled for this analysis. Some data were available from 1985 and 2001; however, data for the entire year were not available, and thus data from these years were not used in the analysis.

The data were sorted by incident date and then compiled by year. Each year was then sorted according to the portion of the pipeline system that leaked; the line pipe, tank farm, or pump station. The tank farm and pump station data were discarded so that the analysis would include only pipeline leaks. In the case where the cause of leak was coded "no data," it was assumed that the leak was in line pipe, and the data were included in the analysis.

After the tank farm and pump station data were removed, the pipeline leak data were sorted again by the nominal diameter of the pipe. In some cases the nominal diameter field was blank, or entered as zero. Where this occurred, the average diameter computed for that year was input.

The number of leaks in each year of record was divided by the average diameter for that year, then by the length of pipelines in service for the year to determine the target figure; the number of leaks per diameter–inch per mile for the year. The average of all the years of record was then taken as the measure of the safety of the pipelines for the period.

The number of pipeline leaks for transmission lines in the United States during the period 1986 to 2000 was 7.9×10^{-5} leaks per diameter-inch per mile per year. The vast majority of the transmission lines included in this data set are buried lines in thawed ground. Data tables are presented in Appendix B.

USA Causes of Pipeline Incidents

The pipeline leak data were sorted by incident type for each year. The published data for pipeline leaks were coded in seven categories – Damage from Outside Forces; Corrosion; Failed Weld; Failed Pipe; Incorrect Operation by Operator Personnel; Malfunction of Control or Relief Equipment; or Other.

The percentage of occurrence for each category was calculated by dividing the number of leaks resulting from that cause for the year by the total number of leaks in the year. The same process was used determine the average percentage for each occurrence type for the period from 1986 to 2000. The causes of pipeline leaks for the period are presented in Table 2.

Table 2 **Causes of Buried Oil and Hazardous Liquid Pipelines, USA, 1986 - 2000.**

Cause of Leak	Percentage of Failures 1986 – 2000
External Damage	34.7
Corrosion Failure	29.9
Other Damage	17.7
Failed Pipe	7.1
Failed Weld	6.2
Incorrect Operation by Personnel	2.4
Malfunction of Control/Relief Equipment	2.0

USA Statistics Comments and Conclusions

It should be noted that the size of the incident (cost, damage, size of spill, etc.) was not accounted for in this analysis. Every incident was treated with the same weighting during the data reduction. It is noteworthy that approximately 65% of the failures resulted from external damage or corrosion.

2. Kuparuk River Unit Aboveground Gathering Pipeline Leak Statistics

Leak data for the crude oil transportation and gathering lines in the KRU, between 1984 and 2001, as well as water line pipelines were analyzed for comparison.

KRU Statistics for Aboveground Gathering Pipelines

The number of leaks in the KRU were analyzed and it was determined that 10 leaks have occurred as a result of corrosion and outside forces. Neither erosion leaks nor leaks at wellheads were included in the leak total. This was so that the statistical data would be comparable to the OPS statistics. Not including the wellhead data was to ensure that only pipeline leaks were considered. Discarding leaks due to erosion failures was to make the data comparable to the OPS data compiled for transmission pipelines. Transmission pipelines by definition transmit treated fluids; sediment has been removed. Most of the KRU lines in this analysis are gathering lines that transmit fluids that may contain sediment, and are thus susceptible to erosion failure. Because the treated liquids flowing through the transmission pipelines do not contain sediment like the gathering pipelines, they are not subject to erosion failures. To include the erosion leaks in the KRU leak history would artificially elevate the statistical leak value when compared to transmission pipelines

The pipeline lengths and diameter for the KRU were tabulated to quantify the number of leaks per diameter-inch per mile. Pipelines between drill sites and facilities at CPF-1, CPF-2, and CPF-3 were included in the analysis, as well as the transmission pipeline to Pump Station 1. The total length of these pipelines is 441 miles and the average diameter is 14.4 inches. KRU pipeline data are tabulated in Appendix B.

Data Reduction Kuparuk River Unit Conclusions

To determine the leaks per diameter-inch mile year, the number of leaks in water and oil pipelines were summed. The number of leaks was divided by the total length of pipelines that were in operation at various periods of time, associated with the start-up of Central Processing Facility 1 (CPF-1), CPF-2 and CPF-3. The length and diameter of pipelines, and their time of service were tabulated from "Line Lists" provided by Phillips. All pipelines considered in this analysis were constructed between 1984 and 1987. Leaks in the KRU were found to occur at a rate of 9.9×10^{-5} leaks per diameter-inch per mile per year during the period 1984 to 2001.

3. Leak Incidence Rate Conclusions

The leak occurrence rate calculated for the aboveground KRU gathering lines is slightly higher than the rate calculated for buried transmission pipelines across the USA. However the rates are very close, and given possible error introduced by the analytical techniques used, the numbers should be considered identical. That is to say, in their operating lives, the KRU aboveground pipelines have performed at the same level of safety as regulated, buried transmission lines during roughly the same period. Although the methods used to calculate the safety statistics were necessarily different because of the nature of the data sets, comparison of the safety statistics to reach this conclusion still seems reasonable.

6.9 Leak Detection

Leak detection will be critical…

Leak detection will be a critical aspect of a buried pipeline on the North Slope, because the pipeline is being put into a potentially unstable environment, and in a location where leaks may not be readily observable.

There are two approaches to detecting pipeline leaks; internal methods and external methods. Internal methods use computer-aided instrumentation systems to measure certain internal pipeline properties to evaluate the probability of a leak having occurred. External methods use sensing systems to directly detect fluids that have escaped the pipeline. The former method does not possess the inherent reliability for detecting leaks that would be required for this application, which includes three-phase flow. It is likely that both types of systems would be operated in parallel to provide a high degree of reliability and certainty that leaks will be detected quickly.

6.9.1 Internal Pipeline Leak Detection Methods

Commercially available computer-aided detection systems utilize the technologies described below. Each method is most effective for single-phase flow (e.g., sales-quality oil). The methods are more complicated and less reliable for multi-phase flow, such as the assumed base case for this study. As such, internal leak detection methods represent an area where technological advances may be necessary to advance the concept.

...internal leak detection methods

... are an area where technological advances may be necessary...

1. Volume or Mass Balance Based Method

In this method, the fluid volume or mass entering and exiting the pipeline are measured periodically, and checked against the amount in storage (line pack). The volume or mass entering and exiting the pipeline should be very nearly equal, the only difference being the variable quantity stored in line pack. If the difference between the quantity entering and exiting, with adjustments for line pack, changes by more than an established tolerance, a leak alarm is generated.

2. Pressure Point Analysis (PPA) Method

This method relies on analyzing data at a single measurement point. Additional points improve performance, but are not essential to the technique. The PPA method can detect leaks in gas and liquid lines and also in some two-phase flow pipelines. PPA detects leaks by extracting signals representative of the current operation and the most recent trends from data taken at a point along the pipeline, determining if the behavior of these two signals contains evidence of a leak, and reporting the results of this procedure to the operator.

3. Rate of Change in Flow or Pressure Method

This method relies on the premise that a large change of flow or pressure at the inlet or outlet indicates a leak. If the rate of change of flow or pressure is higher than threshold within a specific period of time, a leak alarm is generated.

4. Hydraulic Modeling Method

This system involves dynamic mathematical modeling of flow within a pipeline. Leaks are detected based on discrepancies between calculated and measured hydraulic values. The method requires flow, pressure, and temperature measurements at the inlet and outlet of a pipeline segment and additional measurements at intermediate points. The method presents a picture of current pipeline flow conditions using the smoothed SCADA information.

5. Statistical Analysis Methods

Statistical analysis methods are based on detecting changes in the relationship between flow and pressure along the pipeline using measurements at the inlet and outlet rather than using numerical solutions. This technique requires flow, temperature, and pressure measurements only at the pipeline inlet and outlet; however, additional measurements at intermediate points may improve performance and accuracy.

6.9.2 External Pipeline Leak Detection Methods

Available external pipeline leak detection methods are varied and additional methods of detection are being introduced as new technologies emerge. External leak detection methods are an area where technological advances may well be required in order to improve the viability of North Slope buried pipelines.

...external leak detection methods ... another area where technological advances may well be required to improve the viability of North Slope buried pipelines...

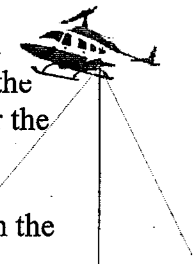
1. Near Pipeline Soil Monitoring

Near pipeline soil monitoring is defined as using one of several physical technologies in the excavation backfill near the buried pipelines to detect leaks. These technologies may be applied where soils are thawed, and are described briefly below.

Diffusion hoses are a network of vapor-permeable tubes buried in the trench with the pipelines. After a period of time the tube is pumped out into a detector that reads the contamination levels in the vapor. The LEOS System relies on this technology to monitor for leaks in the Northstar offshore pipeline.

Tracers use a small amount of gas injected into the fluid stream, and detector probes (either portable or permanent) to detect the tracer gas should it escape the pipeline.

Electro-chemical sensing cables are placed near the pipeline, and locate the leak when the leak "wets" the cable. These cables can detect hydrocarbon liquids or water, but not in combination in a single cable.



LiDAR is similar to radar, except it uses light instead of radio waves. If a semi-permeable tube is buried in a straight line with the pipelines above the water table, it may be possible to detect the contaminate vapors that enter the tube.

Metal oxide semiconductor (MOS) based systems measure fuel vapors in the soil. Clean air has a relatively low electrical conductivity, when reducing gases such as combustible gases are present, the electrical conductivity increases. MOS sensors are a broad-range device designed to respond to the widest possible range of toxic gases.

Sniffer tubes are pipes inserted into the ground, with sensors installed to detect gas lost by the leak.

Optical fiber can be used to detect leaks from many types of liquid pipelines. A continuous cable, it will be "wet" by the leak fluid. The fluid on the outside of the cable will change the refractive properties of the cable and will reduce the light throughput of the cable, thus indicating a leak.

6.9.3 Other External Leak Detection Methods

Other external leak detection methods include geochemical, biosensors, and site characterization and analysis penetrometer system laser-induced fluorescence (SCAPS LIF).

The biosensors are analytical tools in which the sensing element is an enzyme, antibody, or micro-organism, and the transducer is an electrochemical acoustic or optical device. For hydrocarbon detection, biosensors use genetically engineered micro-organism (GEMs) that recognize and report the presence of specific environmental pollutants.

An emerging technology to detect leaks …is the use of satellite based optical systems

to detect such characteristics as substance heat signatures and light absorption spectra.

The SCAPS LIF uses an optical fiber based induced fluorescence sensor system deployed with a standard 20-ton penetrometer to provide three dimensional mapping of the leak area.

These methods are not suited for continual monitoring over the length of a pipeline and are currently impractical for this application. Other, more conventional methods include groundwater and visual monitoring.

1. Groundwater Monitoring

Hydrocarbons can be detected in groundwater using of hydrocarbon detection sensors or liquid phase interstitial detectors. These methods are not generally used for continuously operating leak detection systems on the North Slope due to the extended permafrost areas encountered in the area. Furthermore, these methods provide detection capabilities over very localized areas.

2. Visual Inspection by Personnel

Visual inspection is usually performed either directly by personnel or by the utilization of specialized optical equipment. The visual inspection method most commonly in use on the North Slope is the "drive-by" method where personnel working in the field will report any visual leak than can be seen from the road or from over-flying aircraft. This would not be possible for a buried pipeline in a roadless development.

Another method used on the North Slope is to over-fly the pipelines with forward looking infrared radar (FLIR) that detects the additional heat added to the surroundings by the leak. Remotely operated "drone" aircraft equipped with FLIR are becoming commercially available.

6.9.4 Leak Detection Conclusion

The leak detection solution for a buried pipeline on the North Slope would be determined in the final design and permitting phase, based on the approved design criteria and in accord with the pipeline system and the specific environment in which it is installed. At this time it appears that leak detection would rely primarily on external pipeline leak detection methods combined with visual observations and FLIR. Internal detection methods, particularly on the three-phase line, have yet to be proven.

Leak detection in nearly all of the specific areas discussed above represents one of the most critical aspects of burying pipelines on the North Slope, and certainly represents the field in which there is the greatest need and potential for technological advances.

Section 7. Buried Pipelines for Developments with a Road

Virtually all of the engineering, construction, and operations considerations discussed above are applicable to buried pipelines whether constructed for developments with or without a road. If constructed in conjunction with a road, the pipelines may be constructed alongside the road, within the road, or beneath the road prism.

...considerations unique to a buried pipeline ...

In addition to the considerations discussed above for roadless options, some new considerations are unique to a pipeline that is constructed in conjunction with a road. Some of these are discussed in the following subsections.

...constructed in conjunction with a road

7.1 Increased Impact to the Environment

Additional impacts that will result from constructing this option include the larger affected footprint that will result from placing fill for the road. If the pipeline is installed in the road prism, the net impact is the same as that for constructing a road alone. For reasons of safety, access, operational considerations, and pipeline/road configuration, it will likely be more sensible to bury the pipeline next to the road rather than in or beneath it. If this is the case, the affected footprint of the development's infrastructure will roughly double.

7.2 Vehicular Damage Risk

If pipelines are buried in or next to a road, there is risk of vehicular damage. This risk results from potential impact damage from a vehicle that runs off the road. This risk is likely less for a buried pipeline than for an aboveground line, because of the soil cover over the pipeline. However, there is still some risk to a buried pipeline, particularly if a vehicle runs off the road in summer when soils over the buried line are thawed and soft.

If the pipelines are buried in the road, risks include damage during grading or other construction activities; damage from vehicle strikes if the pipelines heave to the road surface due to frost jacking or upheaval buckling; and damage from vehicles punching through the road due to failure of the roadway soil. These risks can be reduced by placing the pipelines outside the drivelane; however, this also increases project impact because the resulting road/pipeline bed is now substantially wider than a conventional road.

7.3 Drainage Structures

Pipelines buried in a roadway will affect culverts in the road, and bridges across rivers and streams. If installed beneath the culverts, they must be excavated into the underlying tundra soils. If installed above the culverts, the height of the gravel prism must be increased to provide adequate separation between the culverts, and to provide enough cover over the pipelines to satisfy code requirements, provide protection, and to provide vertical restraint. Increasing the height will also increase the width of footprint and volume of the roadway fill, thus increasing environmental impact.

In this configuration, the pipelines would likely be suspended from the road bridge where the road crosses rivers. Separate pipeline bridges parallel to the road and road bridge may also be used.

7.4 Access and Maintenance Considerations

As described previously, maintenance activities are anticipated for any buried pipelines. Should the pipelines be installed in the road prism, the excavation/inspection/repair activities would likely require restrictions in road use, or closure of the road. These activities will disrupt normal and emergency traffic while they are being done, and will also affect access following completion because of the disturbance to the roadway structural fill.

Section 8. Solutions Requiring Technological Advances

The options described above are comprised of concepts that have been applied to some degree within the North Slope oil and gas industry, in the industry in cold regions other than the North Slope, or on the North Slope in applications outside the oil and gas industry. Described in this section are two options that have not been applied in the North Slope oil and gas industry, but represent interesting concepts that warrant consideration at the conceptual level. The options, a structural conduit buried in a roadway and a deep tunnel option, are described in the sections below.

...interesting concepts that warrant consideration at the conceptual level...

8.1 Road Conduit Option

... road conduit option...

In this option, the pipelines would be enclosed in a conductor running the length of the road, buried in the gravel fill prism along the drivelanes. The conductor would be vented to the atmosphere through the side of the road to allow air circulation to remove heat generated by the pipelines, to reduce heating of the surrounding gravel and in-situ soils. Along with the vents, a man-way access would be provided from the gravel surface to access the pipelines.

8.1.1 Design Considerations

Road conduit design issues...

Some of the significant design issues that would need to be resolved to advance this concept are described below.

1. Buried Conduit Construction Concept and Materials

Materials could consist of corrugated metal pipe (CMP), steel pipe, concrete pipe, concrete prefabricated box, or reinforced sheet metal box. There are currently no plastic pipe materials large or strong enough, especially in low temperature arctic installations, for use as a conduit. The shape of the conduit would be a function of the type of material from which it is constructed. It would be cylindrical if made of corrugated metal, steel, or concrete pipe. The cross section could be oval if corrugated metal was used. A square cross section could be manufactured from sheet metal or concrete.

In order to install the pipelines inside the conductor, there must be a horizontal joint to allow access. The bottom half of the conductor must be installed, and support beneath the conduit would be a challenge. Either provisions must be made to allow thawing and compacting the fill, "sculpting" a bed in previously compacted fill that exactly fits the shape of the conduit, or to support the base and haunches with a lean concrete mix that provides support without excessive compaction. Meanwhile the pipelines are strung, lined-up, welded, and coated. The pipelines would then be lowered in, and placed in guided, sliding, or anchored supports, in accordance with design.

The top of the conduit would then be placed, fixed to the bottom of the conduit, and to adjacent sections. Each of these joints would then be sealed to make it watertight. The seams, along with vents and other appurtenances to the conduit are potential pathways for water to enter the system. It is critical that this installation be watertight in order to keep the insulation system integrity intact, minimize pipeline corrosion risk, minimize required maintenance, maintain safety, and to maximize useful life of the structure due to corrosion. Making the installation watertight is one of the more significant design challenges with this option. It will be difficult to seal any conduit option other than welded steel pipe.

...Making the installation watertight...

2. Piping System

The piping must be supported within the conduit to resist both vertical and horizontal (lateral and transverse) loads. Internal supports will rely to some degree on the conduit for support. The level to which the conduit will resist piping loads will rely heavily on the type of material used for the conduit. Vertical loads will be supported on the conduit bottom, likely with some sort of reinforcement. Lateral loads will be resisted by an internal framework or by the conduit, if the conduit is strong enough. CMP is not well suited to bear the large loads generated by the pipelines.

Critical pipe support issues include slugging forces; thermal expansion and anchoring; and surge. The multi-phase production line is subject to liquid slugging which leads to uplifting and horizontal instantaneous loads capable of moving the pipeline. Conventional North Slope design is to strap the pipeline down to the steel horizontal support member and this would be required for this option as well. This would be especially difficult where the pipeline changes direction. In aboveground pipelines, the supports for this condition are oversized, which may be challenging in the confines of a conduit.

Critical pipe support issues...

The pipelines in the conductor would be subject to movement due to thermal expansion. Unlike buried lines that resist expansion due to soil restraint, these lines would require expansion loops and anchors similar to conventional aboveground pipelines. With an expansion loop required at intervals comparable to that of conventional aboveground pipelines, the conductor system would have to be designed to accommodate the movement. Since it would be difficult to make the long radius pipeline bends inside the conduit, expansion loops would need to be built out of custom components in order to make the corners and allow for the pipe movement. Anchors would have to be designed into the conduit pipe supports. This would be no problem with a steel pipe conductor but could be a problem with the CMP or steel box designs.

One option would be for the expansion loops to exit the conduit as required and then re-enter the conduit after the loop. This would result in pipeline segments exposed along the roadway.

3. Air Circulation

...rely on cold air circulation to remove heat from the conduit...

This concept would rely on cold air circulation to remove heat from the conduit. Thermal analysis would be required to verify feasibility of this concept. Use of cold air for chilling in a variety of North Slope applications (such as beneath slab-on-grade buildings) has been largely unsuccessful. Design challenges include maintaining sufficient air flow; preventing snow drifts, hoar frost, and other obstructions from blocking air duct openings; and preventing infiltration of water. Roadway surfaces must be kept free of snow, and vents or manways above the gravel surface would be vulnerable to damage from snow removal equipment.

4. Inspection

Inspection philosophy...

Inspection philosophy would have to be established for this option, as it will have a significant affect on the design and construction. The pipelines must be considered "aboveground," that is, accessible for inspection, maintenance and repair without excavation; or "belowground" in that all inspection would be in-line, and the conduit would be excavated and opened to allow access for inspection, maintenance and repairs.

If treated as aboveground, manways could be constructed in the conduit to allow physical access to the pipelines for inspection, maintenance, and repair. This means the conductor must be sized to allow human access, greatly increasing the size and construction costs. Engineering measures and work procedures would be required to work safely in the enclosed environment.

If treated as belowground, the conduit would be sized to accept the pipelines and necessary appurtenances only, and access would not be possible during normal operations. CD pigs would be necessary to monitor corrosion, and excavation will be necessary to investigate anomalies. Additional inspection may be accomplished using camera probes inside the conduit.

5. Leak Detection and Oil Spill Response

...circulation vents to detect leaks

It may be feasible to use circulation vents to detect leaks. Sensors could detect hydrocarbon vapors in the atmosphere inside the conductor. Additionally, optical inspection equipment portions of the pipe could be inspected at vents and access points. Small leaks would likely be contained inside the conduit, but if the leak was rapid or went undetected for a long period, it could spill outside through vents or other pathways.

Clean-up could be difficult because of possible difficulty in entering the conduit to remove oil without causing arcing and sparking, which could lead to explosion and fire. With a 10-mile long conductor it would be virtually impossible to do a nitrogen purge to remove oxygen preventing an explosive atmosphere at the location of the repair. A baffle system may be necessary to minimize the amount of purge required.

6. Configuration

The layout of the road and pipeline would have to be optimized to allow the two features to coexist. For example, roadway turns do not match the normal turning radius of pipelines. This would cause the roadway to be wider in some spots to cover the pipeline route. Also, the road would have to be widened where pipeline expansion loops were constructed.

Another configuration challenge would be at drainage structures. At culverts, the road prism would be very high to accommodate both the large diameter conduit and large diameter culverts. Depending on the materials of construction, this could be approximately 15 feet or higher at the crossings. The width of the prism would be on the order of 130 feet at the base of the road fill.

8.1.2 Requirements to Advance Road Conduit Concept

The following areas require additional investigation and advancements to further this design concept.

- ***Ventilation***. Natural ventilation to the extent necessary for adequate heat removal could be difficult.
- ***Watertight Seals.*** Development of a watertight conduit, including access ways and vents.
- ***Pipeline Expansion.*** Expansion loops, continuous anchoring, or significant innovation will be required to deal with the thermal forces of the pipelines.

- ***Inspection.*** Inspection in the tight spaces of the conduit could be a challenge. Most inspection would be via pigging.

8.1.3 Summary of Road Conduit Advantages/Disadvantages

Perceived advantages and disadvantages of this concept are below.

Advantages of the road conduit concept include:

- Pipelines are not visible;
- No tundra scar;
- Pipelines will likely have less affect on wildlife passage;
- Pipelines will likely have less affect on cross-tundra travel;
- Summer construction is advantageous in some cases; and
- Cathodic protection is not required.

Disadvantages of the road conduit concept include:

- Will impact construction and maintenance of culverts and bridges;
- Insulation and conduit are required;
- Additional gravel volume and footprint required to maintain safe cover;
- Visual monitoring for leak detection is not sufficient;
- Civil maintenance will be required, especially due to sloughing shoulder;
- Risk of thaw settlement exists;
- Internal inspection (pigs) will be required;
- Will impact traffic during construction and during pipeline maintenance;
- Compaction of winter gravel/thaw settlement of winter gravel could present challenges; and
- External corrosion coating and insulation are required.

8.2 Tunnel Option

... a tunnel excavated through the permafrost soils...

A second concept that may be a viable method for constructing belowground pipelines is to install the pipelines in a tunnel excavated through the permafrost soils. Tunneling is used regularly in mining, transportation, and utility applications, and no insurmountable technical obstacles have been identified that would preclude tunneling through typical North Slope frozen soil conditions. Tunneling has been considered for use on previous North Slope projects, such as the offshore Kuvlum Field. However, no tunneling projects have been constructed to date on the North Slope.

Robert Smith, Ph.D. of the project study team was tasked with developing this option. Development at the conceptual level consisted of utilizing experience and engineering judgment gained on past projects, and consulting tunneling experts regarding the concept. The detailed report of the concept development is presented in Appendix C. This report provides the detailed information that supports the concept and results, which are summarized in this section.

In the tunneling option, the pipelines would be enclosed in a lined tunnel, excavated well below the tundra surface. The tunnel would be ventilated for safety reasons, as well as to circulate cold air to remove heat introduced by the pipelines. Along with the vents, access ports would make the pipelines accessible for inspection and repairs, and a conveyance system, either rail or self-propelled vehicles, would aid construction and operations.

8.2.1 Design Considerations

Some of the significant design issues related to tunnel construction are described below.

1. Tunnel Construction Concept and Materials

The tunneling concept consists of excavating a large diameter (12- to 14-foot) tunnel with tunnel boring machines (TBMs). As the TBMs advance the tunnel, spoils would be removed from the tunnel using a rail or conveyor system. Once the spoils were brought to the surface, they would be spread on spoils disposal areas near the tunnel opening. Shortly behind the TBMs, the tunnel would be lined with a lightweight lining constructed of lightweight (low density aggregate) reinforced concrete. The annulus between the liner and the excavated tunnel wall would be filled. Ideally the filler would be a high-strength, low density, insulating foam that would structurally bond the liner and earth together, while limiting heat transfer from the tunnel into the ground.

A method of conveyance, either a light rail system or self-propelled carriers would be installed in the tunnel to support construction, operations, and maintenance. If a rail system were used, the rails would be set into the floor of the liner. If a self-propelled car system were used, the carriers/trailers would be designed to ride on a wearing surface on the tunnel floor. The transportation system would be used to supply materials to the excavation face, remove spoils, transport construction crews and materials, re-supply other construction activities, provide access to and from the production site, transport operations and maintenance staff and equipment, respond to operational upsets, spills, or leaks, and other activities as required.

...light rail system or self-propelled carriers installed in the tunnel...

Ventilation would be required in the tunnel to provide safe breathing air for personnel, to prevent hazardous or explosive atmospheres from forming in the event of a leak or spill, and to circulate cold air to remove heat lost from the hot pipelines. The ventilation system would be fairly elaborate, likely consisting of vertical access shafts, and ventilation shafts paralleling the main tunnel.

...fairly elaborate ventilation system...

Pipe supports would be fixed to the side of the tunnel lining. Other appurtenances (lighting, sensors, electrical and communications cables, instrumentation, etc.) would also be fixed to the tunnel lining.

After the necessary support structures have been completed in the tunnel, the pipelines would be strung, lined-up and welded at the surface. Segments would be fairly short, then lowered into the tunnel through access shafts, and transported into position using the internal conveyance system. The lines would be lowered-up onto the pipe support hardware, lined-up, tied in, and tested.

Tunneling and construction would likely be broken into a number of spreads, each consisting of crews to perform all the tasks described above (tunneling, lining, etc.) in parallel. The construction would be sequenced into segments, with "down time" to refurbish the TBMs built into the project schedule. The segments would all be tied together to complete the tunnel-mode pipeline system.

Construction of a typical pipeline, which would take a single winter construction season for a conventional, aboveground pipeline would take several years to complete in the tunneling mode. Construction activities would likely take place year-round.

2. Piping System

The suite of pipelines would be supported on pipe support hardware fixed to the tunnel liner. The pipelines would likely be in a stacked configuration along one side of the tunnel, with no more than one or two lines per pipe support. This configuration is shown in Appendix C.

The pipelines would be anchored at intervals of several hundred or a few thousand feet, and lateral movement of the pipelines between the anchors due to thermal expansion would be restricted via closely spaced collars. Other methods of dealing with thermal expansion include excavating rooms or shafts to allow construction of expansion loops, or using a mechanical expansion method.

3. Air Circulation

...cold air circulation

The tunnel would require cold air circulation to remove heat, as well as to provide a safe breathing atmosphere. Thermal analysis would be required during subsequent design phases to ensure the tunnel is stable in the frozen ground. Use of cold air for chilling in a variety of North Slope applications (such as beneath slab-on-grade buildings) has been largely unsuccessful. Design challenges include maintaining sufficient airflow; preventing snowdrifts, hoar frost and other obstructions from blocking air duct openings; and preventing infiltration of water.

4. Inspection

... access may be complicated...

Operations of the pipeline in tunnel mode would obviously be significantly different than that for an aboveground pipeline or a more conventional buried pipeline mode. The line would be available for some visual inspection, but access may be complicated by ventilation/confined space issues, as well as by the limited space in the tunnel. The conveyance system, (rail or otherwise) would be used to access the line, and to move materials and equipment along the lines. Corrosion inspection would almost certainly be via internal devices, since space in the tunnel would be limited, and there would likely not be sufficient space to operate external devices such as those used to inspect aboveground pipelines.

5. Leak Detection and Oil Spill Response

If leaks or spills occurred, they would likely be detected via cameras and sensors installed in the tunnel. It may be feasible to use circulation vents to detect leaks. Leaks or spills would be contained in the tunnel, but cleanup may be difficult because of access, and because of the difficulty of working in a confined space filled with hazardous, explosive vapor.

8.2.2 Requirements to Advance Tunnel Concept

The following areas would require additional investigation and advancement to further this design concept.

- ***Constructability Review.*** Tunneling projects have not been completed in the North Slope. The viability of the concept requires further study.

- ***Cost Estimate.*** Although cost has not been a primary consideration in evaluating the viability of options in this report, the tunnel option would likely be significantly more costly than any other option. Realistic cost estimates, resulting from a more rigorous evaluation than has been conducted in this study, should be completed to provide a solid understanding of the cost of the tunnel option.

- ***Ventilation.*** The ventilation system required for this concept would likely be elaborate, and would be further complicated by the North Slope environment.

- ***Conveyance System.*** The conveyance system selected would have a significant impact on the cost, construction, and operations of the pipelines.

- ***Spoils Disposal.*** The volume of tunnel spoils would be very large. Methods for disposing of this soil must be explored.

- ***Pipeline Expansion.*** Expansion loops, close anchoring, or significant innovation may be required to deal with the expansion of the pipelines.

- ***Inspection.*** Inspection of the lines may require a mix of internal and external methods.

8.2.3 Summary of Tunnel Advantages/Disadvantages

Perceived advantages and disadvantages of the tunnel concept are below.

Advantages of the tunnel concept include:

- Pipelines are not visible on the surface;
- No tundra scar from surface excavation;
- Pipelines will likely have less affect on wildlife passage;
- Pipelines will likely have less affect on cross-tundra travel;
- Year-round construction is likely possible; and
- Cathodic protection is not required.

Disadvantages include:

- Elaborate tunnel construction effort required;
- Significant volume of excavation spoils;
- Elaborate ventilation system required;
- Visual monitoring for leak detection is not sufficient;
- Construction will likely be significantly longer than for aboveground pipelines;
- Confined space risks;
- Corrosion detection and curvature pigs will be required;
- Restricted space inside the tunnel will likely require complicated maintenance and repairs;
- Can't be built in winter due to gravel compaction requirements; and
- External corrosion coating and thermal insulation are required.

Section 9. Construction Cost Estimates

Cost estimating was a minor part of this study. The focus of the study was to identify potential options for burying hot pipelines on the North Slope, assess technical viability of options by working technical issues at a conceptual level, and identifying technical advancements necessary to progress options.

Having completed the above work however, it is unrealistic to ignore the cost of the proposed option. For this reason, conceptual-level cost estimates have been completed for a "conventional" buried pipeline option (bare pipe with very thick insulation layers around the pipe), for the buried conduit option, and for the tunnel option. These estimates are tabulated below (Table 3), along with the cost of conventional North Slope pipelines for comparison. A summary of each option is shown in Table 4.

Table 3 Cost Estimates for Pipeline Options

Option	Unit Cost ($/Mile)	Cost Factor
OPTION A - Elevated Pipelines Adjacent to Road (Base Case)	**$ 2,949,000**	1.0
OPTION B - Belowground Pipelines in Highly Insulated Ditch	**$ 5,858,624**	**1.99**
OPTION C - Belowground Pipelines in Conduit in Road Shoulder	**$ 9,220,240**	**2.61**
OPTION D - Pipelines in Deep Tunnel	**$ 20,248,549**	**6.87**

Table 4 Conceptual Cost Estimate Summary

Conceptual Cost Estimate Summary	
OPTION A - Elevated Pipelines Adjacent to Road (Base Case)	
Item	**Cost per Mile**
Ice/Snow Road Construction	$ 100,000
VSM Installation	$ 275,000
Pipeline Construction	$ 2,574,000
TOTAL	**$ 2,949,000**
FACTOR:	**1.00**
OPTION B - Belowground Pipelines in Highly Insulated Ditch	
Item	**Cost per Mile**
Ice/Snow Road Construction	$ 100,000
Pipeline Construction	$ 2,574,000
Trench costs	$ 139,333
HDPE jacket	$ 929,280
FBE coating	$ 93,133
Board insulation	$ 824,000
Cathodic Protection	$ 21,560
Leak Detection system	$ 190,080
Revegetation	$ 10,800
TOTAL	$ 4,882,187
20 Percent Contingency	$ 976,437
Grand Total	**$ 5,858,624**
FACTOR:	**1.99** (Option B Cost/Option A Cost)
OPTION C - Belowground Pipelines in Conduit in Road Shoulder	
Item	**Cost per Mile**
Pipeline Construction	$ 3,861,000
Beams and Hardware	$ 316,800
CMP Conduit	$ 1,425,600
FBE Coating	$ 93,133
Board Insulation	$ 412,000
Additional Gravel & Earthwork	$ 1,575,000
TOTAL	$ 7,683,533
20 Percent Contingency	$ 1,536,707
Grand Total	**$ 9,220,240**
FACTOR:	**2.61** (Option C Cost/Option A Cost)

Table 4 Conceptual Cost Estimate Summary

Conceptual Cost Estimate Summary	
OPTION D - Pipelines in Deep Tunnel	
Item	**Cost per Mile**
Pipeline Construction	$ 4,270,933
Additional Engineering, Studies, Materials, Procurement & Mob/Demob	$ 1,965,714
Tunnel System	$ 7,854,286
Pads, Spoils, Terminals and Support Facilities	$ 2,782,857
TOTAL	$ 16,873,790
20 Percent Contingency	$ 3,374,758
Grand Total	**$ 20,248,549**
FACTOR:	**6.87** (Option D Cost/Option A Cost)

Assumptions/Limitations:

- All pipeline cost estimates are conceptual level; accuracy is on the order of ±30 Percent. Significant design and construction details that will affect costs remain unworked.
- All pipeline costs are estimated on a "per-mile" basis.
- All pipeline scenarios include three pipelines, 8-, 12, and 24-inches in diameter.
- Aboveground pipelines are insulated with 3 inches of polyurethane insulation in a metal sheath.
- Cathodic protection consists of a continuous sacrificial magnesium anode.
- Trenching costs are based on drill-and-shoot excavation.
- Buried pipeline options consider no removal of excavation spoils or importing of backfill materials. Excavations will be backfilled with excavation spoils.
- For OPTION C, additional cost of drainage structures are not included. This includes additional gravel over culverts, measures to maintain separation from culverts, pipe supports on bridges, etc.
- For OPTION C, cost for mitigating thermal expansion (continuous restraint, expansion loops, etc.) are not included.
- OPTION C includes 2-inches of polyurethane insulation in a metal sheath, as well as 6-inches of extruded polystyrene boardstock insulation.
- No contingency was applied to OPTION A because aboveground construction techniques are conventional practice. A 20 percent contingency has been applied to OPTIONS B, C, and D since they are unproven techniques on the North Slope.

Section 10. Conclusions

Conclusions of this study include:

- Conceptual-level evaluation indicates hot fluid pipelines may be buried in permafrost on the North Slope of Alaska. Existing technology would likely require advancements in several areas before the concept is available for general use.

- The cost of buried pipelines is likely about twice the cost of conventional aboveground pipelines.

- Cost of operating hot fluid pipelines buried in permafrost on the North Slope of Alaska was not estimated for this study. However, the study group concluded that operations costs would be significantly higher than for conventional aboveground pipelines, chiefly because of the certainty of civil repairs, and corrosion investigation and repairs.

- A buried pipeline on the North Slope is likely to have a surface expression (i.e., it is likely to be visible). This is important to understand in case it is counter to the goals of a buried pipeline.

- Solutions relying on unconventional technology such as buried conduits and tunneling do not look promising at this time because of technical and cost factors. These concepts may be developed further to confirm feasibility and to estimate costs.

- Comparison of operational safety statistics of some buried pipelines across America to safety statistics of KRU aboveground pipelines indicates that the operational safety of the two groups of pipelines is at the same level. Burying pipelines in permafrost on the North Slope, for reasons described in this report such as thaw settlement and external corrosion, will likely decrease safety compared to aboveground pipelines on the North Slope or to buried pipelines in unfrozen ground.

Table 5 North Slope Buried Pipeline Configurations Comparisons

North Slope Buried Pipeline Configurations	
Optimized Pipe Insulation / Boardstock Configuration	
Advantages	**Disadvantages**
♦ It utilizes two insulation modes, both of which are configured in conventional thicknesses that may be supplied by traditional vendors.	♦ There is one additional fabrication (or installation) step than if only one type of insulation (either pipe insulation or boardstock) was used.
♦ It includes methods common to North Slope civil construction.	♦ Insulation sheath must keep the pipe insulation dry.
	♦ If saturated, the insulating properties of the polyurethane insulation around the pipelines decrease significantly.
	♦ If saturated, the polyurethane insulation around the pipes yields a corrosive environment.
	♦ It is difficult or impossible to provide secondary corrosion protection to insulated pipelines.
Advantages	**Disadvantages**
♦ It utilizes only boardstock insulation.	♦ Insulation is most effective when used as close as possible to the heat source. The efficiency of this insulation method may be slightly lower than some other configurations.
♦ It is conducive to secondary corrosion protection.	♦ Installation of the boardstock insulation may be difficult under windy North Slope winter conditions.
♦ The pipelines are in direct contact to the soil, so that, when it is thawed, it will conduct electric current and will be capable of providing cathodic protection to the pipelines. Buried pipelines that are covered with pipeline insulation are very difficult to thoroughly cover with cathodic protection because the insulation/sheath impedes flow of electrical current.	
♦ It includes methods common to North Slope civil construction.	

Table 5 North Slope Buried Pipeline Configurations Comparisons

North Slope Buried Pipeline Configurations	
Super-Insulated Pipe Configuration	
Advantages	**Disadvantages**
♦ It simply utilizes pipe insulation, thus removing the North Slope construction step of placing boardstock.	♦ Insulation sheath must keep the pipe insulation dry.
♦ It includes methods common to North Slope civil construction.	♦ If saturated, the insulating properties of the polyurethane insulation around the pipelines decrease significantly.
	♦ If saturated, the polyurethane insulation around the pipes yields a corrosive environment.
	♦ It is difficult or impossible to provide secondary corrosion protection to pipelines insulated in this fashion.
Road Conduit Option	
Advantages	**Disadvantages**
♦ Pipelines are not visible;	♦ Will impact construction and maintenance of culverts and bridges;
♦ No tundra scar;	♦ Insulation and conduit are required;
♦ Pipelines will likely have less affect on wildlife passage;	♦ Additional gravel volume and footprint required to maintain safe cover;
♦ Pipelines will likely have less affect on cross-tundra travel;	♦ Visual monitoring for leak detection is not sufficient;
♦ Summer construction is advantageous in some cases; and	♦ Civil maintenance will be required, especially due to sloughing shoulder;
♦ Cathodic protection is not required.	♦ Risk of thaw settlement exists;
	♦ Internal inspection (pigs) will be required;
	♦ Will impact traffic during construction and during pipeline maintenance;
	♦ Compaction of winter gravel/thaw settlement of winter gravel could present challenges; and
	♦ External corrosion coating and insulation are required.

Table 5 North Slope Buried Pipeline Configurations Comparisons

North Slope Buried Pipeline Configurations	
Tunnel Option	
Advantages	**Disadvantages**
♦ Pipelines are not visible on the surface;	♦ Elaborate tunnel construction effort required;
♦ No tundra scar from surface excavation;	♦ Significant volume of excavation spoils;
♦ Pipelines will likely have less affect on wildlife passage;	♦ Elaborate ventilation system required;
♦ Pipelines will likely have less affect on cross-tundra travel;	♦ Visual monitoring for leak detection is not sufficient;
♦ Year-round construction is likely possible; and	♦ Construction will likely be significantly longer than for aboveground pipelines;
♦ Cathodic protection is not required.	♦ Confined space risks;
	♦ Corrosion detection and curvature pigs will be required;
	♦ Restricted space inside the tunnel will likely require complicated maintenance and repairs;
	♦ Can't be built in winter due to gravel compaction requirements; and
	♦ External corrosion coating and thermal insulation are required.

Section 11. Design Aspects Requiring Technological Advancement

Each of the buried pipelines concepts described in this report includes technical issues where existing technology could be advanced to improve the concept. The improvements may lower cost, increase viability, or improve safety. A listing of these topics is presented below.

- ***Restoration and Revegetation.*** Technology for restoring disturbed ground on the North Slope has advanced significantly since the first developments were constructed. However, substantial room for improvement still exists, and this field should continue to advance.

- ***Insulation Durability.*** The durability and long term performance of insulation, whether fixed to the pipe or direct burial boardstock could be improved.

- ***Insulation Jackets.*** The performance of insulation is greatly improved if it is kept clean and dry. Although this sounds like a simple manner, it has always proved difficult, and there is room for great improvements.

- ***Unconventional Insulation Materials.*** Insulation types other than polyethylene and polyurethane may exist. Alternatives that may be applicable to buried pipelines should be researched.

- ***Corrosion Resistant Insulation.*** Adding corrosion inhibitors or other additives to pipeline insulation to create a non-corrosive environment around the pipe could be a dramatic breakthrough. This concept should be advanced, to determine viability, and potential affects to the insulation properties.

- ***Cathodic Protection.*** This form of secondary corrosion protection is difficult in frozen ground. Performance improvements should be investigated.

- ***Leak Detection.*** Quickly and accurately detecting leaks is a critical component in any buried pipeline design. There is substantial room for improvement in both internal and external leak detection methods.

- ***Pigging Technology.*** The performance of internal inspection devices has been steadily improved in recent years. Improvements are still likely in the future, in the performance of existing technologies, as well as in areas not currently feasible.

- ***Constructability Evaluations.*** Construction methods for burying pipelines on the North Slope should be further developed. Of particular concern are excavation methods, keeping open excavations clear of snow, and removing snow from excavations.

- ***Operations and Maintenance Methods.*** Operations and maintenance of buried pipelines on the North Slope will be challenging. These topics should be advanced along with design topics to improve confidence in buried pipeline concepts.

Section 12. Recommendations

Recommendations for advancing the buried pipeline concept include:

- The technical efforts expended in this study are of a conceptual nature. If buried pipeline concepts are to be advanced, subsequent engineering phases (i.e., front-end engineering, preliminary, feasibility, final design) should be performed to advance the concepts.
- Areas requiring additional technological advancements have been identified in Section 11. These areas should be further developed, ranked, and plans made for advancing those areas that are most likely to provide cost effective solutions.
- An essential part of subsequent phases will be laboratory and/or field testing. Carefully designed, constructed, and operated field tests could more realistically replicate actual conditions, and identify flaws in this technique prior to commissioning an actual pipeline containing hazardous fluids.
- Permitting, land, and wildlife issues related to this topic should be advanced.