# APPENDIX A

## Caen Frost Heave Test Facility

| **Test Facility** | **Caen Frost Heave Test Facility** |
|---|---|
| Location | Caen, Normandy, France |
| Owner | Station de Gel, Centre de Geomorphologie |
| Operator | Station de Gel, Centre de Geomorphologie |
| Participants | Government of Canada: Energy, Mines and Resources, Canada; Natural Sciences and Engineering Research Council; National Energy Board; National Defence; and the following companies: Esso Resources Canada Limited; Foothills Pipe Lines Limited; Gulf Canada Resources; Interprovincial Pipe Line Inc.; Nova Corporation of Alberta; Shell Canada Limited; Transcanada Pipelines (Polar Gas Project); Yukon Pacific Corporation; Government of France: Laboratoire Central des Ponts et Chaussées; Centre National de la Recherche Scientifique; and Sofregaz. |
| Principal Researcher(s) | M. Jaime Aguirre Puente, M. Lucien Faugeres, Centre National de la Recherche Scientifique<br>Dr. Peter Williams, Carlton University |
| Timing / Duration | 1982 – 1993 |
| Purpose | To undertake a full-scale experiment with precise control of the physical, thermal and hydrologic conditions. Does not model any particular field situation or pipeline foundation design. |
| Description of tests | Investigation of frost heave effects on a pipeline buried near the interface of frost susceptible and non-susceptible soils and frozen and unfrozen soil. |
| Test Components | One 273mm diameter pipe section, 18m long, buried at 33cm depth in a highly controlled and instrumented soil test bed. The pipe crossed a vertical interface between silt (frost susceptible) and sand (non-susceptible). A second set of tests was performed on a pipeline laid across a frozen / unfrozen soil interface. The soil bed was 18m long, 8m wide and 1.75m deep. |
| Operating Conditions | The ambient air temperature was controlled to perform freezing cycles (-0.75$^{o}$C) interrupted by thaw cycles (+4$^{o}$C). The pipe temperature remained at -2$^{o}$C during first freeze and thaw cycle & cycled between -5$^{o}$C and ambient temperature during subsequent cycles. A total of 4 freeze-thaw cycles were performed with freeze times in the range 260 to 700 days, and thaw times of 130 to 315 days. |

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| | The second set of tests were performed with a surface temperature of –0.75°C and pipe temperature –5 to –8°C. A period of stress relaxation was incorporated with the pipe at +5°C prior to a further period of freezing. Freezing periods were of the order of 250 days long. |
| Instrumentation | Thermocouples within the soil, flux meters, surface leveling pins, tensiometers, pressure cells, heave tubes, frost depth tubes, TDR moisture content probes, pipe deflection, pipe curvature, pipe strain. Numerous laboratory cell tests also performed on soil specimens. |
| Summary of results | Quantification of frost penetration and soil and pipe heave and thaw settlements for freeze and thaw cycles. Calculation of stresses induced due to pipe curvature. Some evidence to challenge conventional theory relating to continued heaving of already frozen soil and orientation of ice lens formation. |
| Faults, problems, shortcomings | Test configuration not completely representative of expected field conditions – small diameter pipe, vertical boundary interface. Second set of tests across frozen/unfrozen interface experienced thawing of the frozen soil leading to thaw settlement. |
| Requirements for further work | Data has been extensively used to develop and calibrate numerical prediction geothermal and frost heave models. Invaluable data due to the highly controlled test conditions. |
| Reports | As listed. No final report found. |
| Availability / access to data | EMR reports not publicly available. Papers published in abstract form only. ASTIS & AINA call references listed (with abstract) where available. |

**Reference List:**

Frost Heave: Caen experiment results and some practical implications. Atkinson, D. (Student research in Canada's North : Proceedings of the Third National Student Conference on Northern Studies, Ottawa, October 23-24, 1991 / Edited by Walter O. Kupsch and James F. Basinger. Musk-ox, no. 39, special publication, 1992, p. 107)
Abstract only.
ASTIS record 34117.
Languages: English and French
Libraries: ACU G600.M85 NO39 1992
Frost heave is a well studied and documented phenomenon associated with any region subjected to winters the average temperatures for which remain below freezing. This presentation provides a brief theoretical description of the processes associated with and responsible for frost heaving. It will then examine some of the results generated by an experimental facility located in Caen, France that is jointly run by Canadian and French

researchers to study the phenomena. Drawing on these results, implications for engineering concerns in the Canadian North, especially the Mackenzie Valley, will be sketched out. ...

Permafrost : large-scale research at Calgary and Caen / Burgess, M.
(Geos (Ottawa), v. 14, no. 2, Spring 1985, p. 19-22, ill., map)
ASTIS record 16454.
Languages: English
Libraries: ACU
This article details permafrost research in which the Earth Physics Branch of Energy, Mines and Resources (Canada) is involved. Experiments are underway to document the long-term effects of frost heave on buried pipelines, both insulated and non-insulated. (ASTIS)

PIPELINES AND FROST HEAVE. 1985. Proceedings of a Conference, Caen, France. Sponsored by Energy, Mines and Resources, Canada and Ministère de l'Urbanisme et du Logement, France. 75 pp. Carleton University, Ottawa, Canada. (contains following articles by project team: Experimental Observations of Differential Heaving and Thaw Settlement around a Chilled Pipeline; M.W. Smith, Soil Freezing and Frost Heaving at the Caen Experiment; S.R. Dallimore, Laboratory Characterization of Frost Heaving of Caen Silt; Dominique Blanchard and Michel Frémond, Behaviour of Soils in the Arctic; W.H. Bowes, Bending Stresses in Pipe due to Frost Heave; R.J. Kettles, Soil - Pipeline Interaction: A Review of the Problem; B. Ladanyi and G. Lemaire, Caen Pipeline Experiment: A Back-Analysis of Observations Made during the First Year of the Test.)

Experimental observations of Differential Heaving and Thaw Settlement around a Chilled Pipeline. Based on report for Earth Physics Branch, Energy, Mines & Resources, Canada, 1982.

Soil Freezing and Frost Heaving at the Caen Experiment. Smith, M. W. Geotechnical Sciences Laboratories, Carleton University.

Laboratory Characterisation of Frost Heaving of Caen Silt. Dallimore, S. R. Geotechnical Sciences Laboratories, Carleton University.

Ice Lens Formation at a Silt-Sand Interface. Smith, S.L. & Williams, P. J. Canadian Geotechnical Journal. Vol. 32. pp.488-195. 1995.

Detailed Observations on the nature of Frost heaving at a Field Scale. Smith, M.W. & Patterson, D. E. Canadian Geotechnical Journal. Vol. 26. pp.306-312. 1989.

Observations and Significance of Internal Pressures in Freezing Soil. Smith, M. W. & Onysko, D. Proceedings 5th Canadian Permafrost Conference, Laval, Quebec City. 1990.

Ice Lens Orientation around a Chilled Buried Pipe. Smith, S. L. & Williams, P. J. Proceedings 5th Canadian Permafrost Conference, Laval, Quebec City. 1990.

Geotechnical Aspects of Northern Gas Pipeline Design. Nixon, J. F., Sortland, K. A. & James, D. A. Proceedings 5th Canadian Permafrost Conference, Laval, Quebec City. 1990

The France-Canada Joint Study of Deformation of an Experimental Pipeline by Differential Frost heave. Williams, P. J., Riseborough, D. W. & Smith, M. W. Proceedings 2nd International Offshore and Polar Engineering Conference, San Francisco, USA. 1992.

Pipelines buried in freezing soil: a comparison of two ground-thermal conditions. Riseborough, D.W., P.J. Williams and M.W. Smith, 1993. Proc. of the 12th International Conference on Offshore Mechanics and Arctic Engineering Volume V: Pipeline Technology, American Society of Mechanical Engineers, Book No. G00681-1993, pp. 187-193.

Further references listed at the following website:
http://www.freezingground.org/GSLNetwork/pipepapers.htm#RP
http://www.freezingground.org/GSLNetwork/france.htm

# APPENDIX B

## Calgary Frost Heave Test Facility

| **Test Facility** | **Calgary Frost Heave Test Facility** |
|---|---|
| Location | University of Calgary campus, NW Calgary, Alberta, Canada |
| Owner | Canadian Arctic Gas Study Limited (CAGSL) |
| Operator | CAGSL 1974-1978<br>Foothills 1978-1986<br>EMR involved since 1982 |
| Participants | CAGSL, Foothills, Northern Engineering Services Limited (Engineering) |
| Principal Researcher(s) | W. A. Slusarchuk, J. I. Clark, J. F. Nixon, J. R. Elwood, L. E. Carlson |
| Timing / Duration | 1974 – 1986 |
| Purpose | Objectives of the full scale field buried pipeline tests:<br>1. Observe and monitor the performance of a 4 foot diameter pipeline buried in frost susceptible (silty) soil when operating at approximately 10$^{o}$F,<br>2. Determine the effect of increasing overburden pressure and replacing some of the frost susceptible soil with gravel in reducing frost heave,<br>3. Obtain a better understanding and appreciation of the role of water availability in the development of frost heaving around a chilled gas pipeline, and<br>4. Relate the field results to those of the laboratory frost heave and model tests in order to develop, check and redefine a predictive capacity. |
| Description of tests | Investigation of frost heave effects on a pipeline buried in unfrozen frost susceptible soil. |
| Test Components | Initially 4, 12.2m long, 1.22m diameter pipe sections buried in natural frost susceptible soil. Pipe configurations where: (1) Control Section with 760mm natural backfill cover, (2) Deep Burial Section with 1675mm cover, (3) Gravel Section with 900mm gravel bedding and 760mm natural backfill cover, and (4) Restrained Section as (1) but restrained by load-controlled system. 2 pipe sections added in 1978, insulated with 15mm polyurethane covering, with similar configuration as (1) and (3) above. Berms added to control and deep burial sections in 1975. |
| Operating Conditions | Pipes operated at constant temperature of –10$^{o}$C. |
| Instrumentation | Instrumentation included in-soil thermisters, heat flux transducers, heave gauges and piezometers. Comprehensive geotechnical, laboratory and small scale |

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| | pipe test program also performed. |
| Summary of results | Quantification of frost penetration and soil and pipe heave for each pipe section. Observation of mitigative effects of different burial configurations. Low pore suctions generated ahead of freezing front. No observation of continued heaving of already frozen soil. Development of frost front consistent with geothermal analysis as long as water migration is considered. Frost susceptibility is sensitive to small changes in clay content. Heave generated decreases according to configuration - control, deep burial, gravel, restrained, insulated control, insulated gravel. Lower clay content in soil at gravel section may contribute to lower measured heave. |
| Faults, problems, shortcomings | Control section terminated in 1977 due to space requirements for building work. Berm added to control and deep burial sections hindered interpretation of long term effects. |
| Requirements for further work | Exceptional data available for testing and calibrating geothermal and frost heave numerical models. Generally accepted to be the most valuable and comprehensive full-scale test site undertaken to date. |
| Reports | As listed. No final report found. |
| Availability / access to data | Large collection in AINA and NEB archives. ASTIS & AINA call references listed (with abstract) where available. |

**Reference List:**

**Interim report on frost effects study [volume I and volume II]** / Northern Engineering Services Company Canadian Arctic Gas Study Limited [Sponsor]
Calgary, Alta. : Northern Engineering Services Co., 1975.
ASTIS record 49796.
Languages: English
Libraries: ACU TJ930.P62.I573.1975
This report describes the test facilities and laboratory equipment associated with the Frost Effects Study Program. The study program involves three phases; the field test facility, the laboratory frost heave cells and the laboratory model pipeline. In addition to the equipment description, the results from the three phases of the program collected to January 1975 are presented. The predicted and observed temperatures, heaves and pore pressure for the field test facility are presented and discussed. Results from the 4 inch frost heave cells are included, together with the data collected from the laboratory model pipeline tests. A method of predicting pipe heave is presented. The method employs the laboratory heave-pressure relationships to predict pipe heave with time. In general, good

agreement is obtained between predicted and observed heave, from penetration and pore pressures for the field test facility. The results presented in this second interim report represent part of an ongoing study, and the program of data collection and analysis is continuing. ...

**Frost heave information pursuant to National Energy Board requests of May 11, 12 and 14, 1976** / Northern Engineering Services Company Canadian Arctic Gas Study Limited [Sponsor]
Calgary, Alta. : Northern Engineering Services Co., 1976.
ASTIS record 31779.
Languages: English
Libraries: ACU TJ930.P62.F76.1976
The information contained in this report is provided in response to specific requests made by the National Energy Board during cross-examination of the Geotechnical Panel. The following information is provided: Item #1 .... Additional information on frost heave prediction procedures, and update of frost heave measurements and predictions for the four buried pipe test sections at the Calgary Test Facility. Item #2 .... Elevation measurements of riser rods on buried pipe test sections at Sans Sault Test Facility. Item #3 .... Equivalent depth of burial of Restrained Section with largest load as compared to the Deep Burial Section with present surcharge load on it. Item #4 .... Question relating to equal spacing of data points on a graph showing heave of Restrained Section plotted against frost penetration depth below pipe. The specific data points in question were those when the frost penetration depth was between 7 and 8 1/2 feet below the pipe. Item #5 .... Provide smoothed curves for plot of pipe heave against frost penetration depth below pipe for the four buried pipe test sections at the Calgary Test Facility.

**Field test results of operating a chilled, buried pipeline in unfrozen ground** / Carlson, L.E. Ellwood, J.R. Nixon, J.F. Slusarchuk, W.A.
(The Roger J.E. Brown memorial volume : proceedings of the Fourth Canadian Permafrost Conference, Calgary, Alberta, March 2-6, 1981 / Edited by H.M. French. NRCC - National Research Council of Canada, no. 20124, 1982, p. 475-480, figures)
ASTIS record 12193.
Languages: English
Libraries: ACU GB641.A2.C36 4TH 1981
In order to study the behaviour of a chilled, large-diameter pipeline buried in frost-susceptible ground, a field test facility was constructed in Calgary, Alberta. This facility, which contained four non-insulated test sections of pipe, 1.2 m in diameter, buried in frost-susceptible soil, has been operational since March 1974. Two insulated sections of pipe 1.2 m in diameter were installed in late 1978. This paper describes the layout of the test site and the geometry of the test sections. Results are presented, of the growth of the frost bulb around the pipe sections, together with the heave of the pipe sections and the soil around the pipe. The results of these full-scale frost heave field tests have aided in developing an understanding of frost heaving around a chilled pipeline. They have indicated the effects of increased overburden pressure and frost penetration rate on the rate of frost heave.

**Response to Dr. P.J. Williams' report on possible heave of chilled gas pipeline** / Northern Engineering Services Company Canadian Arctic Gas Study Limited [Sponsor]
Calgary, Alta. Northern Engineering Services Ltd., 1976.
38, 15 leaves : ill. ; 29 cm.
ASTIS record 31667.
Languages: English
Libraries: ACU TJ930.P62.R47 1976
Dr. P.J. Williams has restated his position with regard to frost heaving in a "Report on Possible Heave of Chilled Gas Pipeline" dated 4 February, 1976. The report was prepared in response to the rebuttal evidence presented by Drs. J.I. Clark, R.L. Harlan, P. Hoekstra, N.R. Morgenstern and W.A. Slusarchuk on behalf of Canadian Arctic Gas Pipeline Limited before the Berger Commission on October 16, 1975. From the report it is evident that major areas of disagreements and concerns persist between Williams and CAGPL. The two major areas of disagreement are: (1) Magnitude of Shut off Pressure .... (2) Amount of Heave in Frozen Ground ....

**Interim report on frost effects study** / Northern Engineering Services Company Canadian Arctic Gas Study Limited [Sponsor]
Calgary, Alta. : Northern Engineering Services Co., 1974.
61, [89] leaves : ill. (some folded), 1 map ; 29 cm.
ASTIS record 31813.
Languages: English
Libraries: ACU TJ930.R47.NO975
The temperature of the gas in the pipeline will be chilled to below 32 degrees Fahrenheit for most of its length where it passes through areas of permafrost. In these areas where the pipeline passes through unfrozen ground the effect of freezing the ground around the pipe must be assessed. ... The frost effects study program which was developed was conveniently divided into three activities as follows: 1. Full scale field buried pipeline tests, 2. Laboratory frost heave tests, and 3. Laboratory model buried pipe tests. The overall objective of the frost effects study program was to obtain information which would assist in better defining the areas of potential frost heave along the route, the possible magnitude of the heaving problem in these areas, and the effectiveness of various remedial measures, if heaving was demonstrated to be a problem. ...

**Field test results of a chilled pipeline buried in unfrozen ground** / Slusarchuk, W.A. Clark, J.I. Nixon, J.F. Morgenstern, N.R. Gaskin, P.N.
In: Proceedings - International Conference on Permafrost, 3rd, Edmonton, Alberta, July 10-13, 1978. - Ottawa : National Research Council of Canada, 1978-79, v. 1, p. 877-883, ASTIS record 1952.
Languages: English
Libraries: ACU GB641 .I56 3RD 1978 V.2
... Four test sections of 1.22 m diameter gas pipeline were buried in a frost susceptible silt, and have been maintained at a temperature of -10 deg. C for about 3 years. This paper describes the instrumentation installed around the pipe sections to monitor frost penetration, frost heave and pore water pressure. Results are presented showing the

growth of the frost bulb around the pipe sections, together with heaving of the pipe and the soil around the pipe. ...

**In situ frost heave testing using cold plates** / Nixon, J.F. Ellwood, J.R. Slusarchuk, W.A.
(The Roger J.E. Brown memorial volume : proceedings of the Fourth Canadian Permafrost Conference, Calgary, Alberta, March 2-6, 1981 / Edited by H.M. French. NRCC - National Research Council of Canada, no. 20124, 1982, p. 466-474, figures)
ASTIS record 12192.
Languages: English
Libraries: ACU GB641.A2.C36 4TH 1981
... The design, fabrication, installation, and instrumentation of several 0.76 m diameter cold plates are described. Instrumentation includes heave measurement rods, thermistors, and earth pressure cells. These plates have been successfully installed and operated in the south Yukon and Calgary. Results from these tests provide a bridging between small-scale laboratory testing and eventual frost heave design for large diameter, buried, chilled gas pipelines. Results from one of two cold plate installations at the pipeline research facility in Calgary are presented in detail, and brief comparisons are made with the behaviour of full-size pipeline test sections. The in situ cold plate test provides valuable test data within a few months that are a valuable aid to long-term frost heave predictions.

**Permafrost : large-scale research at Calgary and Caen** / Burgess, M.
(Geos (Ottawa), v. 14, no. 2, Spring 1985, p. 19-22, ill., map)
ASTIS record 16454.
Languages: English
Libraries: ACU
This article details permafrost research in which the Earth Physics Branch of Energy, Mines and Resources (Canada) is involved. Experiments are underway to document the long-term effects of frost heave on buried pipelines, both insulated and non-insulated. (ASTIS)

**Frost Heave and Thaw Settlement Test Facilities** / Carlson, L. E.
Pipelines and Frost heave. 1985. Proceedings of a Conference, Caen, France. Sponsored by Energy, Mines and Resources, Canada and Ministère de l'Urbanisme et du Logement, France. 75 pp. Carleton University, Ottawa, Canada.

# APPENDIX C

## Fairbanks Frost Heave Test Facility 1

| **Test Facility** | **Fairbanks Frost Heave Test Facility 1** |
|---|---|
| Location | Chena Hot Springs Road, Fairbanks, Alaska, USA |
| Owner | Northwest Pipeline Company<br>Foothills Pipelines Ltd |
| Operator | Northwest Pipeline Company<br>Foothills Pipelines Ltd |
| Participants | Northwest Pipeline Company<br>Foothills Pipelines Ltd<br>Alaska International Contractors (construction)<br>Fluor Engineers and Constructors (project management) |
| Principal Researcher(s) | W. A. Slusarchuk, J. R. Elwood, L. E. Carlson, D. E. Fielder |
| Timing / Duration | 1978 - |
| Purpose | Objective of tests to find the right combination of burial techniques – gravel replacement, pipe insulation, shallow burial & installation of chill pipes to maintain frozen soil. |
| Description of tests | Investigate the performance of pipeline buried in permafrost & non-permafrost terrain. |
| Test Components | 10 test pipe sections of 1.2m diameter pipe:<br>Section 1 – 120’ long bare un-insulated in native soil backfill. Used as control section.<br>Section 2 – 2” urethane insulation buried on compacted and backfilled in native soil.<br>Section 3 – trapezoidal trench lined with 6” foam insulating boards, bedded with compacted granular fill. Non-frost susceptible backfill.<br>Section 4 – bare un-insulated, on 3’ bed of non-susceptible material.<br>Section 5 – wrapped in 2” urethane insulation on compacted gravel bed. Native soil covering pipe & gravel backfill.<br>Section 6 – quick-freezing of adjacent soil using natural convection devices. Evaluation of mitigation of frost heave by creating total permafrost condition. Bare pipe in native soil with installation of Thermo-Tubes from Shannon Wilson of Seattle along trench. Chill tubes contain 50% methanol, 50% water.<br>Section 7 – 2” urethane insulation on 1’ non-frost susceptible bedding, covered with 1’ compacted gravel & backfilled with native soil.<br>Section 8 – 4” urethane insulation 3’ non-frost susceptible bedding and thermo-tube installation.<br>Section 9 – bare un-insulated 400’ long buried partly in |

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| | permafrost, partly in frost susceptible soil. Instrumented to indicate stress effects. West end backfilled with native soil, east end compacted gravel bedding, covered with gravel & backfilled with native soil.<br>Section 10 – Bare uninsulated 40" long wholly in permafrost similar to Section 9 east end.<br>The site was reactivated in 2000 with 36" diameter pipe buried in permafrost and unfrozen soil. |
| Operating Conditions | Pressurized to 665-675psi and chilled to 8 to 15$^{o}$F. |
| Instrumentation | Temperature sensors in ground, heave rods, load cells to measure soil pressure exerted on the pipe, pore water pressure, heat flux transducers on pipe and in soil. Strain gauges on Section 9 pipe to detect deformity. |
| Summary of results | No results found in public domain. |
| Faults, problems, shortcomings | Unknown |
| Requirements for further work | |
| Reports | As listed. |
| Availability / access to data | 1 trade publication article found |

**References List:**

Frost heave test facility: simulating, solving freeze-thaw problems for proposed gas line (Alaska construction & oil, v. 21, no. 3, Mar. 1980, p. 18-20, ill.)
(Northern development, v. 12, no. 2, Mar./Apr. 1980, p. 4-6, photos.)
Also published under title: Gas line test bed monitors frost heave, in Northern development, v.12, no.2, March/April 1980, p.4-6.
ASTIS record 4025.
Languages: English
Libraries: ACU NFSMO HC107 .A45 A43
In a seven-acre site ... near Fairbanks, pressurized, chilled air circulates through a test facility devised to determine what effects frost heaving might have on the proposed Alaska Highway gas pipeline. HC107 .A45 A43

**Frost Heave and Thaw Settlement Test Facilities** / Carlson, L. E.
Pipelines and Frost heave. 1985. Proceedings of a Conference, Caen, France. Sponsored by Energy, Mines and Resources, Canada and Ministère de l'Urbanisme et du Logement, France. 75 pp. Carleton University, Ottawa, Canada.

# APPENDIX D

## Fairbanks Frost Heave Test Facility 2

| **Test Facility** | **Fairbanks Frost Heave Test Facility 2** |
|---|---|
| Location | Chena Hot Springs Road, Fairbanks, Alaska, USA (Site of old Northwest & Foothills Pipelines test facility) |
| Owner | Japan Science and Technology Agency |
| Operator | Japan Science and Technology Agency |
| Participants | Japan Science and Technology Agency<br>University of Alaska, Fairbanks<br>Hokkaido University, Japan<br>AMEC Earth &Environmental |
| Principal Researcher(s) | S. L. Huang, S. Akagawa, J. Oswell |
| Timing / Duration | 1999 - |
| Purpose | Objectives are: (1) Investigate the thermal influence of the pipeline and the resulting thermal characteristics developed along the pipeline in response to the operation of the chilled pipeline, (2) Study the frost heave characteristics of the pipeline resulting from differential heave across the permafrost-thawed soil transition. Frost heave aspects that are investigated include foundation heave, overburden, heave characteristics and pipeline movement. |
| Description of tests | Investigate the thermal influence and performance of a pipeline buried across an interface of shallow and deep permafrost. |
| Test Components | One test pipe section, 105m long, 0.9m diameter, 8.5mm wall thickness, X65 grade steel. 0.9m cover to top of pipe. Trench backfilled using dry sand to pipe crown topped with crushed insitu soil to the surface. 30m length of pipe placed in shallow permafrost (2-3m depth), 75m in unfrozen ground (deep permafrost at 7-8m depth). |
| Operating Conditions | Nominal pipe operating temperature –10$^{o}$C, with approximately 2$^{o}$C temperature rise between inlet and outlet. |
| Instrumentation | 3 thermister fences placed along the length of the pipe from 1 to 6m from pipe axis and to 8m depth. Permafrost temperature –0.08 to –0.25oC indicating unstable slowly degrading permafrost regime. Instrumentation included 150 thermisters, 40 strain gauges at 11 locations along pipeline, 28 heave rods welded to top of pipe, 5 heave gauges below pipeline, several other types of soil settlement devices. |

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| Summary of results | 3 years of thermal data available on the temperature regime below and around the pipe. Pipeline movement measured using heave rods. Pipe showed initial settlement prior to chilling, with higher values in permafrost – effect of construction disturbance. Maximum absolute pipeline heave over 3 years of chilling was 0.197m in unfrozen soil, 0.049m in frozen soil. |
| Faults, problems, shortcomings | Non reported |
| Requirements for further work | It is understood that further data will be published in the near future. |
| Reports | As listed. |
| Availability / access to data | It is understood that further data will be published in the near future. |

**Reference List:**

Field Investigation of Soil Heave by a Large Diameter Chilled Gas Pipeline Experiment, Fairbanks, Alaska. Huanh, S. L., Bray, M. T., Akagawa, S. & Fukuda, M. ASCE Journal of Cold Regions Engineering, Vol 18, No. 1, pp. 2-34, March 2004.

# APPENDIX E

## Inuvik Hot Oil Line Test Facility

| **Test Facility** | **Inuvik Hot Oil Line Test Facility** |
|---|---|
| Location | 2 miles north of Inuvik, NWT, 3000' east of Mackenzie River |
| Owner | Mackenzie Valley Pipe Line Research Limited |
| Operator | Canadian Bechtel Limited contracted to construct and operate the facility |
| Participants | Atlantic Richfield Canada Limited, BP Oil Limited, Elf Oil Exploration and Production Canada Limited, Gulf Oil Canada Limited, Hudson's Bay Oil and Gas Company Limited, Imperial Oil Limited, Interprovincial Pipeline Company, Shell Canada Limited, Standard Oil Company of British Columbia Limited, Texaco Exploration Company, Trans Canada Pipe Lines Limited, Transmountain Oil Pipeline Company, Valvoline Oil Company of Canada Limited. |
| Principal Researcher(s) | Rowley, G. Watson, W. Slusarchuk (NRC) |
| Timing / Duration | 1969 - 1972 |
| Purpose | Primary objective was to study the technological and economic feasibility of constructing a 48" diameter crude oil pipeline from the north slope of Alaska through the Yukon and Northwest Territories to Edmonton, Alberta. Specifically related to the transport of warm oil in permafrost zones. |
| Description of tests | Evaluate insulating methods regarding heat radiation during operation & oil cooling during shutdown, feasibility of start-up after shutdown, stresses generated by pipeline expansion due to heat, vibration frequencies and amplitudes of elevated pipeline under wind and operating conditions, movement of pipe loop during operation. |
| Test Components | 2000' long experimental closed loop test section, 48" diameter. 3 methods of construction – pipe supported on pile bents, pipe covered by berm and pipe buried in permafrost. Half of the loop was straight with pipe constructed in a gravel berm or gravel a pad 2-5' thick. The return section was supported above ground on 16" wooden piles following a zig-zag pattern with three 12 & two 6 degree bends in 1000' length to allow thermal expansion. Piles installed in 20" holes to 16' depth. Pipe allowed to slide over Teflon coated supports. Pile supports 70' apart. Insulation coating tested in buried & above ground sections – polyurethane 2 & 4" thick & Polyken tape wrapped, Lexan General Electric, 2" thick, |

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| | Styrofoam Bolster Blocks & Polyurethane foam with polyethelene jacket. Also a 4" diameter insulated pipe buried at 2' depth to investigate direct contact with warm permafrost. Insulation was 2" polyurethane foam with polyethylene jacket. |
| Operating Conditions | Operated by pumping warm oil through system. Temperature gradually increased to max 160$^{o}$F, with cooling tests at intervals, with both winter and summer testing. |
| Instrumentation | Temperature probes inserted into the pipe and to 10' depth in the soil below and adjacent to the pipe. Strain gauges attached to the surface of the pipe at points of expected maximum stress. Accelerometer sensors to record wind induced vibrations in the above ground section. Longitudinal and transverse movement rods welded to the pipeline for survey. Probing of the active layer to measure permafrost degradation during summer. |
| Summary of results | Reports listed on ASTIS suggesting that comprehensive data is available on the effect of warm pipelines on permafrost degradation. |
| Faults, problems, shortcomings | |
| Requirements for further work | |
| Reports | Numerous reports listed on ASTIS database, but not found at AINA. |
| Availability / access to data | |

**Reference List:**

Feasibility study, 1972 : back-up data : volume 18 : Geotechnical studies, pipeline construction, stations & terminals, communications, operations & maintenance / Mackenzie Valley Pipe Line Research Limited
Calgary, Alta. : Mackenzie Valley Pipe Line Research Limited, 1972.
1 v. (various pagings) : ill., maps ; 30 cm.
ASTIS record 31989.
Languages: English
Libraries: ACU TJ930 .R47 NO.266
[This document consists of several different reports with different corporate and personal authors. The titles and authors of these reports are as follows:] 18-1 Effects of ground ice variability and resulting thaw settlement on buried warm-oil pipelines, Speer, T.L., Watson, G.H., and Rowley, R.K., 1972. 18-2) Texaco permafrost density logging report, O'Connell, L.P., and Freeborn, W.D., Texaco Exploration Canada Ltd., 1972. 18-3) Interim report, Thermal conductivity measurements of frozen and thawed permafrost from the Inuvik areas, Slusarchuk, W.A., MVPLRL, 1972. 18-4) Final report, Thermal

conductivity measurements of frozen and thawed permafrost from the Inuvik area, Slusarchuk, W.A., MVPLRL, 1972. 18-5) Gathering, handling and preparing permafrost samples for thermal conductivity measurements in Inuvik, N.W.T., Greebe, F., MVPLRL, Spring 1972. 18-6) Thermal conductivity measurements in Inuvik and Ottawa, Greebe, F., MVPLRL, 1972. 18-7) A computer based system for borehole file maintenance and generalized retrieval, Crandlemire, G.W., Computer Sciences Canada Ltd., 1972. 18-8) Investigation of a Mackenzie River crossing near Sans Sault Rapids, Watson, G.H., MVPLRL, 1972. 18-9) Site investigation for insulated road experimental section near Inuvik, N.W.T., Watson, G.H., MVPLRL, 1972. 18-10) Vertical and lateral pile load tests in permafrost, Rowley, R.K., Watson, G.H., and Ladanyi, B., MVPLRL, 1972. 18-11) Results of pressuremeter tests at the Inuvik test site, Ladanyi, B., MVPLRL, 1972. 18-12) Design of laterally loaded piles in permafrost, Ladanyi, B., MVPLRL, 1972. 18-13) Performance of a warm oil pipeline buried in permafrost, Watson, G.H., Rowley, R.K., Slusarchuk, W.A., MVPLRL, 1972. 18-14) Performance of a 48-inch warm oil pipeline supported on permafrost, Rowley, R.K., Watson, G.H., Wilson, T.M., Auld, R.G., MVPLRL, 1972. 18-15) Instrumentation around a warm oil pipeline buried in permafrost, Slusarchuk, W.A., Watson, G.H., Speer, T.L., MVPLRL, 1972. 18-16) Determination of some frozen and thawed properties of permafrost soils, Watson, G.H., Rowley, R.K., & Slusarchuk, W.A., MVPLRL, 1972. 18-17) Pile installation evaluation and load testing program at Dawson City, Yukon Territory, for Becker Drills Limited, Winn, R.H., Rogers, G.W., Dames & Moore, 1972. 18-18) Interim report on frozen core testing, Civil Engineering Department, University of Saskatchewan, 1972. 18-19) Settlement analysis of Inuvik uninsulated berm section, Rowley, R.K., and Watson, G.H., MVPLRL, 1972. 18-20) Simulation of surface energy exchange, Skjolingstad, L., MVPLRL, 1972. 18-21) Automatic temperature recording and data storage system, Skjolingstad, L., MVPLRL, 1972. 18-22) Data summary, Inuvik test facility, Skjolingstad, L., MVPLRL, 1972. 18-23) Thermal simulator studies, Skjolingstad, L., MVPLRL, 1972. 18-24) Construction cost development economic comparisons of Prudhoe Bay to Edmonton versus Tuktoyaktuk to Edmonton, Schroeder, W.W., MVPLRL, 1972. 18-25) Construction cost development Tuktoyaktuk to Edmonton, Schroeder, W.W., MVPLRL, 1972. 18-26) Stations and terminals annual capital investment schedule, Stamberg, J.C., MVPLRL, 1972. Communications annual capital investment schedule, Stamberg, J.C., MVPLRL, 1972. Annual operating and maintenance cost schedule, Stamberg, J.C., MVPLRL, 1972.

Feasibility study : 1971 : back-up data : volume 6 - below ground design / Mackenzie Valley Pipe Line Research Limited
Calgary, Alta. : Mackenzie Valley Pipe Line Research Limited, 1971.
1 v. (various pagings) : ill., maps ; 30 cm.
ASTIS record 31975.
Languages: English
Libraries: ACU TJ930 .R47 NO.414
[This document consists of several different reports with different corporate and personal authors. The titles and authors of these reports are as follows:] 3-1) Preliminary report, underground pipe line in permafrost test facility, Moreau, B.L., Williams Brothers

Canada Limited, May 25, 1971. 3-2) Belowground design study, Hochstein, S.L., Sanders, M.D., and White, C.H., Continental Pipe Line Company, December, 1971.

Feasibility study : 1971 : back-up data : volume 5 - above ground design / Mackenzie Valley Pipe Line Research Limited
Calgary, Alta. : Mackenzie Valley Pipe Line Research Limited, 1971.
ca. 500 leaves : ill. ; 30 cm.
Contains : Inuvik 48-inch loop, August 15, 1970 - January 2, 1972 : Final report.
ASTIS record 31974.
Languages: English
Libraries: ACU
Two above-ground construction techniques were used for the 2,000-foot long, 48-inch diameter test loop at Inuvik, N.W.T. This report evaluates the thermal and mechanical performance of these techniques, describes the test facilities and summarizes the operating history. Pipe movement and corresponding induced stresses are analyzed with the aid of survey data obtained throughout the test period. Pile movement is similarly assessed. Thermal data obtained included ambient, air temperature, surface and sub-surface ground temperature, oil and insulation temperatures, weather data and soil thermal conductivities. A discussion of temperature measuring systems is provided. The capability of a simulator model to compute thermal performance in permafrost systems is studied in some detail by comparing observed and computed temperatures. Data on depth of thaw and settlement of the insulated and uninsulated pipe in the berm are presented and discussed.

Feasibility study : 1971 : back-up data : volume 4 - above ground design / Mackenzie Valley Pipe Line Research Limited
Calgary, Alta. : Mackenzie Valley Pipe Line Research Limited, 1971.
1 v. (various pagings) : ill., maps, plans ; 30 cm.
ASTIS record 31973.
Languages: English
Libraries: ACU
[This document consists of several different reports with different corporate and personal authors. The titles and authors of these reports are as follows:] 2-1) Design concepts report, Termina, J.J., Cities Service Oil Company, September, 1971. 2-2) Design criteria report, termina, J.J., Cities Service Oil Company, December, 1971. 2-3) Analysis of above-ground, zig-zag configuration, Termina, J.J., Cities Service Oil Company, March, 1972. 2-4) Stress criteria report, Walker, G.E., Shell Pipe Line Corporation, October 8, 1971. 2-5) Allowable stress criteria - moment-curvature relationship, Walker, G.E., Shell Pipe Line Corporation, March 13, 1972. 2-6) Inuvik pipe curvature and settlement report, Walker, G.E., Shell Pipe Line Corporation, December 30, 1971. 2-7) Terrain typing for Inuvik test site, Mollard, J.D., J.D. Mollard and Associates Limited, January, 1972. 2-8) Inuvik soil tests summary, Watson, G.H., Mackenzie Valley Pipe Line Research Limited, March, 1972. 2-9) Inuvik berm pipe support conditions, Speer, T.L., and Watson, G.H., Mackenzie Valley Pipe Line Research Limited, September, 1971. 2-10) Inuvik pile load tests, Watson, G.H., and Rowley, R.K., Mackenzie Valley Pipe Line Research Limited, March, 1972. 2-11) Soil and permafrost data report-Inuvik above ground test loop,

Fujino, T.J., Ripley, Klohn & Leonoff Alberta Ltd., January 11, 1971. 2-12) Survey data report-Inuvik above ground test loop, Harper, T.R., Ripley, Klohn and Leonoff Alberta Ltd., January 8, 1971.

Research at Inuvik. Mackenzie Valley Pipe Line Research Limited. 1970. TJ930. P62.M32.1970 C.1

# APPENDIX F

## Mountain River / Sans Sault Rapids Frost Heave Test Facility

| **Test Facility** | **Mountain River / Sans Sault Rapids Frost Heave Test Facility** |
|---|---|
| Location | Located on the west bank of the Mackenzie River, at the confluence of Mountain & Mackenzie Rivers just upstream of Sans Sault Rapids, 65 miles NW of Norman Wells, NWT. |
| Owner | Northwest Project Group (NPG)<br>Canadian Arctic Gas Study Limited (CAGSL) from 1972 |
| Operator | 1970-1973 |
| Participants | NPG<br>CAGSL<br>Northern Engineering Services Limited (Engineering) |
| Principal Researcher(s) | L. G. Williams (construction & operation), D. Dabbs (Research), Hardy Associates (Geotechnical) |
| Timing / Duration | 1970 – 1973 |
| Purpose | Purpose of the Arctic Test Facility:<br>1. To demonstrate the feasibility of the chilled gas pipeline design. To show that with appropriate design, reasonable construction care and proper revegetation techniques, natural gas pipelines can be constructed and operated safely in high ice content permafrost without adverse effect to the environment.<br>2. To provide a means of field verification of computer programs, designed to predict changes both in flowing gas temperatures and soil temperatures around the pipeline.<br>3. To provide a means of studying methods of maintaining the stability of the pipe, backfill and right-of-way (including revegetation techniques) after disturbance by pipeline construction. It was recognized that such measures were most important between time of construction and time of operation of the chilled gas pipeline.<br>4. To determine suitable operating and testing procedures<br>5. To better understand northern construction problems with repect to construction techniques, weather, transportation, logistics and communication. |
| Description of tests | Pipeline buried in ice rich permafrost, chilled operation with periods of warmer gas. Also investigation of the effect of inactive sections to simulate delays in chilled operation. Winter road construction, piled foundations and excavation methods also evaluated. |
| Test Components | 2 pipe loops – buried cold loop & cycling loop, 48” diameter pipe interconnected with 16” above ground |

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| | pipe. One section supported above ground on piles with the other sections buried at 8' to bottom of the pipe. Trenches approx. 5' wide, 8' deep. 7 inactive sections also installed, 42" diameter, 80' long, except one section 48" diameter, 16' long. All buried to 8' average in variety of topography:<br>Section 1 thermocarst area, flat poorly drained, wet, test for floatation.<br>Section 2 sloping bank of Mountain River, 15-16 deg, test for instability of north facing bank. Vertical ice lenses signify recent slope movement.<br>Section 3 across seasonally flowing creek, reasonable flow during spring run off, test for flotation and erosion problems.<br>Section 4 low lying poorly drained.<br>Section 5 low lying semi muskeg zone.<br>Section 6 east facing slope of Mackenzie River 8-10 deg slope test for instability.<br>Section 7 adjacent to active section 2 (cold loop) where organic peat is 8-10' thick. |
| Operating Conditions | Cold loop: 3, 500' sections operated at 20 to 25$^{o}$F, reduced to 5 to7$^{o}$F after 1 year. Cycling loop: 2, 500' sections operated at 25$^{o}$F with short warmer periods at 44$^{o}$F. |
| Instrumentation | Silicon diode sensors with copper constantan thermocouples used to check accuracy of the primary system, thermocouples installed in ditching test areas and vicinity of inactive sections, strain gauges to monitor structural response of cold and cycling loops and riser rods used for surveying pipe movement. |
| Summary of results | The ground next to the cold loop pipe did not thaw during summer and the depth of the active layer was less than at inactive pipes, but was present. Thawing of the permafrost at the cycling loop occurred within a few hours of warming the air above freezing, most rapidly in summer. Water could not escape from ice rich backfill and the pipes became buoyant and showed some upward movement. Geothermal predictions were verified successfully against test sections. Very little or no pipe movement recorded generally. The inactive sections allowed the active layer to extend to below the top of pipe at the end of summer, in some cases to below the buried pipe. |
| Faults, problems, shortcomings | Strain gauges were sensitive to atmospheric humidity and led to large errors – no attempts to correlate observed stresses with pressure, temperature or pipe movement. |

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| Requirements for further work | Useful data on construction operations and stability of pipes installed in permafrost. Limited data on frost heave or thaw settlement. Also invaluable data relating to practical aspects of pipeline construction and effects of delayed operational start-up. Extensive revegetation studies providing valuable demonstration of construction and operation effects in ice rich permafrost. |
| Reports | As listed. |
| Availability / access to data | ASTIS & AINA call references listed (with abstract) where available. |

**Reference List:**

Final report : Arctic Test Facility, Sans Sault, N.W.T. : volume 1 - general, December 1973 / **Northern Engineering Services Company** **Canadian Arctic Gas Study Limited** [Sponsor]
Calgary, Alta. : Northern Engineering Services Co., 1973.
[69] leaves ; 28 cm.
ASTIS record 31828.
Languages: English
Libraries: ACU TJ930 .R47 NO.989
... The overall objective of the Arctic Test Facility was to provide information necessary for the development of engineering design, construction and operation procedures for a safe and reliable pipeline through permafrost areas, which would have a minimal effect on the natural environment. With respect to the pipeline, information was required re: Leaving the pipe inactive for one or more seasons prior to going into operation, operation of a chilled gas line in permafrost areas, and the problems which may arise from operating for short periods at temperatures above 32 degrees Fahrenheit. Additional information was also desired with respect to the design, construction and long term performance of structure foundations, and the effects of disturbance on the permafrost terrain. The facility needed to be large enough to obtain information relative to the logistics of supplying men, equipment and materials to the site, and to the actual construction methods such as clearing, ditching, pipe laying, backfilling and the restoration of disturbed areas. The problems associated with the construction of temporary winter access roads also needed to be evaluated. ..

General report, Arctic Test Facility, Sans Sault, N.W.T. : draft / **Northern Engineering Services Company** Canadian Arctic Gas Study Limited [Sponsor]
Calgary, Alta. : Northern Engineering Services Co., 1974.
50, [33] leaves : ill. (some col.), maps ; 29 cm.
Contains 20 folded illustrations.
ASTIS record 31829.
Languages: English

Libraries: ACU TJ930 .R47 NO.988
... This report discusses the Sans Sault Test Facility which was constructed during the winter of 1970-71 and operated continuously to January, 1973. The research programs carried out during the construction and operation phases of the Test Facility related to construction practices, the change in ground thermal regime around buried operating and inactive or dormant pipes, the geotechnical behaviour of the permafrost and related behaviour of the pipe, the revegetation of disturbed areas, and the cathodic protection of the pipe in permafrost. On the basis of the results of the studies undertaken at the Test Facility, it is considered that the feasibility of a chilled gas pipeline design has been demonstrated, i.e., with appropriate design, reasonable construction care and proper revegetation techniques, natural gas pipelines can be constructed and operated safely at temperatures below 32 degrees F in permafrost terrain without adverse effect to the environment.

Report on geothermal and meteorological studies, Arctic Test Facility, Sans Sault, N.W.T. / **Northern Engineering Services Company** **Canadian Arctic Gas Study Limited** [Sponsor]
Calgary, Alta. : Northern Engineering Services Co., 1974.
ix, 60, [121] leaves : ill. (some folded), 1 map ; 29 cm.
Mostly graphs.
ASTIS record 31830.
Languages: English
Libraries: ACU TJ930 .R47 NO.987
This report deals with the geothermal and meteorological studies undertaken at the Sans Sault Test Facility, N.W.T. Initial field reconnaissance for site selection was undertaken during June and July, 1970, construction began that fall, the Facility became fully operational in March, 1971, and data collection ended in January, 1973. ... The major studies at the Facility were undertaken at a cold loop and a cycling loop. ... Ground temperatures were measured around the buried pipe sections. These temperatures were used in the geothermal computer program verification studies by comparing measured and predicted temperatures. The measured temperatures were also used to establish the depth of the active layer over the pipe and in the adjacent right-of-way at various times of the year. Active layer studies were undertaken at the buried pipeline sections, under gravel pads, and in disturbed and undisturbed areas. In these studies the temperature and depth of the active layer was measured. Cold winter ambient air was circulated with a blower through a group of pipe piles placed in permafrost. Ground temperatures were measured around these ventilated piles and around an adjacent non-ventilated control pile. Temperatures inside other pipe piles under buildings were also measured. The amount of heat flowing into or out of the ground was measured at several sites associated with the revegetation studies. ... The meteorological studies carried out consisted of measuring several meteorological parameters such as maximum and minimum daily air temperatures, wind speed and direction, snow cover, sunshine, barometric pressure and relative humidity.

**Frost heave information pursuant to National Energy Board requests of May 11, 12 and 14, 1976** / Northern Engineering Services Company Canadian Arctic Gas Study Limited [Sponsor]
Calgary, Alta. : Northern Engineering Services Co., 1976.
ASTIS record 31779.
Languages: English
Libraries: ACU TJ930.P62.F76.1976
The information contained in this report is provided in response to specific requests made by the National Energy Board during cross-examination of the Geotechnical Panel. The following information is provided: Item #1 .... Additional information on frost heave prediction procedures, and update of frost heave measurements and predictions for the four buried pipe test sections at the Calgary Test Facility. Item #2 .... Elevation measurements of riser rods on buried pipe test sections at Sans Sault Test Facility. Item #3 .... Equivalent depth of burial of Restrained Section with largest load as compared to the Deep Burial Section with present surcharge load on it. Item #4 .... Question relating to equal spacing of data points on a graph showing heave of Restrained Section plotted against frost penetration depth below pipe. The specific data points in question were those when the frost penetration depth was between 7 and 8 1/2 feet below the pipe. Item #5 .... Provide smoothed curves for plot of pipe heave against frost penetration depth below pipe for the four buried pipe test sections at the Calgary Test Facility.

Mountain River test site : recommended methods and procedures for terrain investigation and testing / **R.M. Hardy and Associates**
Edmonton, Alta. : R.M. Hardy & Assoc., 1970.
14, [7] leaves : 1 map ; 30 cm.
ASTIS record 31801.
Languages: English
Libraries: ACU TJ930 .R47 NO.957
The object of installing inactive pipe sections is to assess the consequences of leaving a backfilled trench for one or two summers without any chilled gas being put through the pipe. We should attempt to find out under what conditions we can lay inactive pipe without fear of severe right-of-way degradation or pipe distress and, at the other extreme, what conditions of terrain should be avoided at all cost. In between these two extremes are conditions where an inactive pipe may be left for some time but certain precautions during construction will be required, particularly as regards the backfilling. There are 500 feet of 42 inch diameter steel pipe at the test site intended to be used in inactive sections. ... The desired results can best be achieved by attempting to obtain a maximum variation in: soil types, ground ice conditions, topography and previous land use. Some variation in the native vegetation is also desirable.

Additional soil testing arctic test facility, Mountain River, N.W.T. / **R.M. Hardy and Associates** Williams Brothers Canada Limited [Sponsor]
Edmonton, Alta. : R.M. Hardy and Assoc., 1972.
13, 3 leaves, [115] leaves of plates : col. ill. ; 29 cm.
Mostly tables and graphs.
ASTIS record 31812.

Languages: English
Libraries: ACU TJ930 .R47 NO.984 V.1
R.M. Hardy and Associates Ltd. has been authorized by Williams Brothers Canada Ltd. to undertake a limited program of additional testing on selected soil samples from the vicinity of the Arctic Test Facility, Mountain River, N.W.T. This report is intended to be an Addendum to our report "Subsurface Conditions, Active and Inactive Test Sections, Arctic Test Facility, Mountain River, N.W.T." August 31, 1971. In addition, one soil sample from Test Hole 633 (located in the Ox-bow Lake) was also tested in this program.

Northwest Project Mountain River test site : cold & cycling loops, sections 1,2,3 & 4 test hole logs / **R.M. Hardy and Associates** **Northwest Project Study Group** **[Sponsor]**
Edmonton, Alta. : R.M. Hardy and Assoc., 1971.
[2] leaves, [228] leaves of plates : ill., 1 map ; 29 cm.
ASTIS record 31804.
Languages: English
Libraries: ACU TJ930 .R47 NO.954
This report consists of 228 tables which describe soil conditions and analyses of the Northwest Project Mountain River test site; both laboratory data and field data are described. (ASTIS)

Soil and permafrost conditions, Mountain River test site, N.W.T., E-1928, July 24, 1970 / **R.M. Hardy and Associates** **Williams Brothers Canada Limited** **[Sponsor]**
Edmonton, Alta. : R.M. Hardy & Assoc., 1970.
ca. 150 leaves : ill., maps ; 29 cm.
Appendix D : Preliminary botanical report - Sans Sault Rapids test area by R.G.H. Cormack.
ASTIS record 31800.
Languages: English
Libraries: ACU
... R.M. Hardy & Associates Ltd. undertook an investigation of a proposed test site situated at the confluence of the Mackenzie and Mountain Rivers, Northwest Territories. It is planned to use the site to install a pipeline test facility in order that the construction and operation of a large diameter natural gas pipeline in permafrost areas can be studied over a period of time. ... Briefly, the conditions desired at the test site are: a wide variety of soil and ground ice conditions, some organic terrain, a water course that could be blocked or dammed, exposures of subsoil along rivers or creeks, "thermokarst" lakes or ponds, a source of dry borrow material (including gravel), a good barge off-loading site. Some recently cleared seismic lines, reasonable assessibility to scheduled air and water transportation.

Mountain River test site : recommended methods and procedures for terrain investigation and testing / **R.M. Hardy and Associates**
Edmonton, Alta. : R.M. Hardy & Assoc., 1970.
14, [7] leaves : 1 map ; 30 cm.
ASTIS record 31801.
Languages: English

Libraries: ACU TJ930 .R47 NO.957
The object of installing inactive pipe sections is to assess the consequences of leaving a backfilled trench for one or two summers without any chilled gas being put through the pipe. We should attempt to find out under what conditions we can lay inactive pipe without fear of severe right-of-way degradation or pipe distress and, at the other extreme, what conditions of terrain should be avoided at all cost. In between these two extremes are conditions where an inactive pipe may be left for some time but certain precautions during construction will be required, particularly as regards the backfilling. There are 500 feet of 42 inch diameter steel pipe at the test site intended to be used in inactive sections. ... The desired results can best be achieved by attempting to obtain a maximum variation in: soil types, ground ice conditions, topography and previous land use. Some variation in the native vegetation is also desirable.

Mountain River field logs, March 1971, E-1928 / **R.M. Hardy and Associates**
Northwest Project Study Group [Sponsor]
Edmonton, Alta. : R.M. Hardy and Assoc., 1971.
ca. 300 leaves : ill. ; 29 cm.
ASTIS record 31805.
Languages: English
Libraries: ACU TJ930 .R47 NO.945
These field logs document the findings of test holes drilled at the Mountain River site. It contains both laboratory data and field data soil descriptions. (ASTIS)

Soil conditions : trenching test areas, Mountain River site, E-1928-8 / **R.M. Hardy and Associates** Northwest Project Study Group [Sponsor]
Edmonton, Alta. : R.M. Hardy and Assoc., 1971.
9, 4, 4 leaves, 15 leaves of plates : ill., 1 map ; 28 cm.
ASTIS record 31806.
Languages: English
Libraries: ACU TJ930 .R47 NO.947
This report describes the soil conditions at three areas selected for trenching tests, carried out during March of 1971, in the vicinity of the Arctic Test Facility at Mountain River. A preliminary report, in letter form, was sent to Williams Brothers Canada Limited on April 14, 1971. The locations of the three test areas are shown ....

Report on terrain investigations, arctic test facility, Mountain River, N.W.T., E-1928-2 / **R.M. Hardy and Associates** **Northwest Project Study Group** **[Sponsor]**
Edmonton, Alta. : R.M. Hardy and Assoc., 1971.
1 v. (various pagings) : ill. (some col.), maps ; 29 cm.
Re-draft of June 7, 1971.
Six folded illustrations attached.
ASTIS record 31807.
Languages: English
Libraries: ACU TJ930 .R47 NO.984 V.1
This report covers the work done in the field and in the laboratory by R.M. Hardy & Associates Ltd. for the Arctic Test Facility, Mountain River, N.W.T., during the period

November 11, 1970 to January 31, 1971. A further report will be issued to cover the work carried out during March, 1971. ... After a decision had been made to proceed with the construction of the Arctic Test Facility at this site, a soil and terrain investigation was planned to provide detailed information on the soil and ground ice conditions in the immediate vicinity of the active pipeline test sections and also at the seven inactive test sections.

Terrain investigations, arctic test facility, Mountain River, N.W.T. / **R.M. Hardy and Associates** Northwest Project Study Group [Sponsor]
Edmonton, Alta. : R.M. Hardy and Assoc., 1971.
19 technical drawings ; 75 x 117 cm folded to 20 x 28 cm.
Drawings to accompany report of July 29/71 contained in envelope. This is an only copy.
ASTIS record 31808.
Languages: English
Libraries: ACU TJ930 .R47 NO.984 V.1
These drawings present information on soil profiles and stratigraphy for the Mountain River test facility region. Information is derived from test holes and trench wall logs. Below 8 foot depth, interpolation between test holes was necessary. Test holes were drilled in November 1970. Datum for elevations is the arctic test facility datum. (ASTIS)

Report on terrain investigations, arctic test facility, Mountain River, N.W.T., volume 1, July 29, 1971 / **R.M. Hardy and Associates** **Northwest Project Study Group** [Sponsor]
Edmonton, Alta. : R.M. Hardy and Assoc., 1971.
1 v. (various pagings) : ill. (some col.), maps ; 30 cm.
ASTIS record 31809.
Languages: English
Libraries: ACU
This report covers work done in the field and in the laboratory by R.M. Hardy & Associates Limited for the Northwest Project Study Group at the Arctic Test Facility, Mountain River, N.W.T. during the period November 11, 1970 to January 31, 1971. A further report will be issued to cover the field work carried out during March of 1971. ... The object of the first investigation and report was simply to assess the suitability of the site for an Arctic Test Facility. The conditions desired at this test site included: a wide variety of soil and ground ice conditions, some organic terrain, a water course that could be blocked, thermokarst lakes or ponds, a source of dry borrow material, and reasonable access to scheduled air and water transportation. ...

Report on subsurface conditions active and inactive test sections, arctic test facility, Mountain River, N.W.T. / **R.M. Hardy and Associates** **Northwest Project Study Group** [Sponsor]
Edmonton, Alta. : R.M. Hardy and Assoc., 1971.
3 v. (various pagings) : ill. (some col.), maps ; 29 cm.
Volume 1 is accompanied by 14 folded drawings; volumes 2 and 3 consist of charts and tables.
ASTIS record 31810.

Languages: English
Libraries: ACU TJ930 .R47 NO.978 V.1
The attached report ... presents the results of soils and permafrost investigations and laboratory testing carried out in the field, and in our Edmonton laboratory, for the above project. Due to the large number of test hole logs and laboratory report sheets, this report has been bound in three volumes. Volume I contains the text of the report, maps, plans showing the test hole locations, charts, descriptive diagrams, photographs and a discussion of the variations which can be experienced in soil water content. Volume II contains the test hole logs and explanatory material on the symbols used on the test hole logs, the Radforth System for describing muskeg, the National Research Council system for describing ice in soils, and a brief review of the Atterberg System of classifying fine-grained soils. Volume III contains grain size analysis charts. ...

Terrain study, Mountain River, N.W.T. / **R.M. Hardy and Associates** **Northwest Project Study Group** [Sponsor]
Edmonton, Alta. : R.M. Hardy and Assoc., 1971.
2 v. (various pagings) : ill. (some col.), maps ; 29 cm.
ASTIS record 31811.
Languages: English
Libraries: ACU TJ930 .R47 NO.977 V.1
This report covers work done in the field and in the laboratory by R.M. Hardy & Associates Limited for Williams Brothers Canada Ltd., engineers for the Northwest Project Study Group in the vicinity of their Arctic Test Facility at Mountain River, N.W.T. The field work was performed during the period March 20 to April 2, 1971. ... The objectives of this drilling program ... included: obtaining more information on soil and ice types, studying certain terrain conditions e.g., thermokarst features, a statistical analysis of results from a large number of test holes, a study of the efficacy of certain in-situ testing methods, a study of the effects of various methods of clearing on depth of thaw, a study of the behaviour of certain foundation types during the spring and summer, an evaluation of the use of Gandhal frost tubes for measuring depth of thaw, a soils investigations for a trenching test program, provision of back-up services for other consultants as requested, and an investigation of the relative value of various sampling techniques and drilling methods which had not been used previously in this program. ...

Interim report - Arctic test facility, Mountain River, N.W.T. / **Williams Brothers Canada Limited** Gas Arctic-Northwest Project Study Group [Sponsor]
Calgary, Alta. : Williams Brothers Canada Ltd., 1972.
1 v. (various pagings) : ill. (some col.) ; 30 cm.
ASTIS record 31463.
Languages: English
Libraries: ACU TJ930 .P62 I567 1972
... The chief elements of the Arctic Test Facility are the Active Test Sections, buried sections of 48 inch diameter pipe through which air at subfreezing temperatures is circulated continuously. A part of the Active Test Sections is designed to provide the capability of circulating air at above freezing temperatures so that the effect of such temperatures can be observed. These events are termed "Cycling Tests". Many other

studies relating to construction and operation of a gas pipeline in the arctic environment are also performed at the Arctic Test Facility and are described in detail in this report. These studies include meteorological observations, construction studies, terrain investigation, vegetation studies, and corrosion/cathodic protection studies. ... Although this report deals mainly with three cycling tests undertaken to date, a limited amount of data have been included for the Cold Loop, as well as information on results obtained from other studies conducted at the test site.

**Developments and research on northern gas pipelines in Canada** / Walker, G.W.
Calgary, Alta. : Canadian Arctic Gas Study Ltd., 1973.
10 leaves : 3 ill. ; 28 cm.
Presented at the International Gas Union, World Gas Conference, 12th, Nice, France, June 1973
ASTIS record 30447.
Languages: English
Libraries: ACU **TJ930 .P62 W34 1973**
Considering the unique conditions of the Arctic, the large distance and large volumes of gas to be moved, several alternate modes in addition to the vapour phase gas pipeline for transportation of the Arctic gas to the Canadian and U.S. markets have been evaluated. These included: (1) Liquefaction of the gas and moving it to the markets as LNG by pipeline, railway and airplanes. (2) Conversion to methanol and moving it by pipeline. (3) "Dense Phase" gas pipelining at operating temperatures from 200 degrees K. (-100 degrees F.) to 166 degrees K. (-160 degrees F.) and pressures from 6.894 MN/sq m (1000 psi) to 13.788 MN/sq m (2000 psi). These investigations concluded that the conventional buried vapour phase gas pipeline has an economic advantage over any of the above-mentioned alternatives. Consequently the research work has been oriented toward the problems associated with the design, construction and operation of a large diameter, high pressure gas pipeline. It has further been found that since the northern half of the proposed pipeline will cross areas of permafrost soils, some of which become unstable when thawed, the flowing gas temperature should be maintained below the freezing point of water. Thus the research work was further oriented towards the problems associated with a chilled gas pipeline in the permafrost areas and included studies in the following principal fields: (1) thermodynamics of gas flow (2) geotechnical and ground stability problems (3) surficial geology (4) ground temperature evaluation (5) protection of the environment (6) construction techniques (7) metallurgy. ... (Au)

# APPENDIX G

## Nordegg Test Facility

| Test Facility | Nordegg Test Facility |
|---|---|
| Location | Nordegg, Alberta, Canada. Location of the existing Edson Mainline Pipeline |
| Owner | Alberta Gas Trunkline Limited (AGTL)<br>Canadian Arctic Gas Study Limited (CAGSL) from 1972 |
| Operator | AGTL & CAGSL |
| Participants | AGTL & CAGSL |
| Principal Researcher(s) | EBA Engineering |
| Timing / Duration | 1971 – 1973 |
| Purpose | To provide data for interpretation of ground temperature and heat flux readings adjacent to an operational pipeline |
| Description of tests | Monitoring of thermal regime associated with operation of the existing Edson Mainline Pipeline system. |
| Test Components | 42" bermed loop section and the adjacent 30" mainline sections of pipeline. |
| Operating Conditions | Gas operated at above freezing temperature |
| Instrumentation | Thermal instrumentation in the soil surrounding the pipeline section |
| Summary of results | No results published. |
| Faults, problems, shortcomings | Not appropriate terrain or operating conditions to provide information on frost heave. |
| Requirements for further work | Thermal measurements used in early mathematical modeling of heat transfer. Data could be reviewed for further numerical model development. Considered a secondary data source. |
| Reports | As listed. |
| Availability / access to data | ASTIS & AINA call references listed (with abstract) where available |

**Reference List:**

Geotechnical engineering, Nordegg thermal research site / **E.W. Brooker & Associates Ltd.** Gas Arctic Systems Study Group [Sponsor]
[S.l.] : Elmer W. Brooker & Assoc. Ltd., 1971.
13, [40] leaves : ill. ; 28 cm.
ASTIS record 31826.
Languages: English
Libraries: ACU TJ930 .R47 NO.990
This report describes geotechnical conditions at the Nordegg Berm Thermal Research site operated by Gas Arctic Systems study group. A thirty inch main gas line near Nordegg,

Alberta and a 42 inch bermed experimental loop have been instrumented to study thermal aspects of soil and pipeline behavior. This date will ultimately be correlated with theoretical predictions from a mathematical model in the hope of verifying the usefulness of the model for application in an Arctic environment. ... The purpose of this investigation is to provide subsurface stratigraphic details to assist in interpretation of ground temperature and heat flux readings obtained from instrumentation previously installed by others. ... The nature of the backfill adjacent to the two pipes was also examined, and nuclear instruments installed in undisturbed soil to allow rapid determination of moisture content and density profiles. Sufficient laboratory testing was carried out to classify the various soil types identified at the site and allow an estimate of thermal soil properties based on existing correlations and data published by others.

# APPENDIX H

## Norman Wells Chilled Gas Test Facility

| Test Facility | Norman Wells Chilled Gas Test Facility |
|---|---|
| Location | Norman Wells, NWT, Canada. Located on east flank of Mackenzie Valley, gentle slope uphill of a lake |
| Owner | Gas Arctic Systems (GAS)<br>Canadian Arctic Gas Study Limited (CAGSL) from 1972 |
| Operator | GAS & CAGSL |
| Participants | CAGSL<br>EBA Engineering (engineering)<br>EW Booker & Associates (engineering – geotechnical)<br>Battelle Columbus Laboratories (engineering – thermal)<br>Williams Brothers (construction) |
| Principal Researcher(s) | EBA Engineering, D. E. Fielder, NESL |
| Timing / Duration | 1971 – 1973 |
| Purpose | The Norman Wells Natural Gas Pipeline Research facility was constructed in order to provide a source of quantitative data characteristic of construction and operation of a large diameter pipeline in permafrost regions. |
| Description of tests | Operation of chilled and warm buried pipelines in ice rich permafrost. Quoted cost $750k including construction, 1 yr operation & associated soils test program. |
| Test Components | 4 operating pipe modules, 48” diameter, 120’ long, with bermed and ditched sections. Also 2, 42” diameter sealed static pipes to represent post-construction, pre-operation conditions. |
| Operating Conditions | 4 operating section divided into: Hot berm (HB 65$^{o}$F), hot ditch (HD 65$^{o}$F), cold berm (CB 15$^{o}$F) & cold ditch (CD 15$^{o}$F) sections. |
| Instrumentation | Resistance temperature detectors, thermocouples, thermisters, plate foot settlement gauges, pneumatic piezometers, insitu nuclear moisture density probes and measurements of active layer thickness by probing to the permafrost table. |
| Summary of results | The test site settled an average 8” in areas of light activity away from pipe sections by the end of the first summer. Permafrost table regressed 6” from pre-construction active layer of 12-18”. Cold pipe modules showed some slumping of the berm before chilled operation. Thawing did not penetrate to below the pipe bottom so no settlement or heave recorded before start-up. After start-up, vertical movement at the edges of the berm showed heave up to 0.3’ then settlement 0.5’ during |

| | |
|---|---|
| | the following summer. No movement of the backfilled half ditch despite thawing to 5' depth in summer 1972. One pipe module was held down by 10 frost anchors, but mobilized 1.5-2" giving a calculated heave pressure of 0.53tsf (7.4psi). Unfrozen soil extended just to bottom of pipe for short duration and was enough to initiate large uplift forces on refreeze. Hot pipe modules showed pipe settlement of 0.8' at the hot berm and 0.4' at the hot ditch. Static pipe modules showed lateral spreading and slumping of the berm material during the 1st & 2nd thaw seasons. Depth of thaw was measured at 6' (2.5' below bottom of ditch) leading to 0.5' pipe settlement. Comparison of thaw depth profiles for different types and degrees of surface disturbance: fully disturbed, partially disturbed, burn areas, surface shields gave 36" in undisturbed areas to >70" for fully disturbed. Thaw settlement prediction with Morgenstern & Nixon 1-D model shows good correlation. |
| Faults, problems, shortcomings | The hot ditched pipe floated during spring run-off due to buoyancy of the plenum end. No anchoring was fitted due to late delivery of anchor saddles. The pipe was lowered back to the specified position by jetting below the plenum and with addition of metal ballast. Frost anchors then installed at ends of each pipe section to prevent uplift before operation. Berms slumped from 20-30" cover to 12-24" by end of summer 1971. |
| Requirements for further work | Good thermal data and some information on the effects of berm performance and thaw settlement. Data could be used to develop and calibrate geothermal models. Limited data on frost heave. |
| Reports | As listed. |
| Availability / access to data | ASTIS & AINA call references listed (with abstract) where available |

**Reference List:**

Gas Arctic Project Norman Wells natural gas pipeline research facility : Instrumentation manual of operating instructions / **PEMCAN Services (Pipeline Engineering and Management Services of Canada)** Gas Arctic Systems Study Group [Sponsor]
Calgary, Alta. : PEMCAN Services, 1971.
[83] leaves (14 folded) : ill. (some folded) ; 29 cm.
Cover title: Gas Arctic Systems Study Group Norman Wells natural gas pipeline research facility : instrumentation manual of operating instructions, November 10, 1971.
ASTIS record 31868.

Languages: English
Libraries: ACU
This manual describes the operating procedures that are to be employed to take and record readings on the instruments placed in the soil at the Norman Wells Research Facility. The required frequency of reading of each of the instruments is set out. The following instruments are covered by this manual: (a) Troxler nuclear probes, (b) Terra Tec settlement sensors, (c) Terra Tec piezometers, (d) Plate foot settlement gauges, (e) Surface settlement gauges, (f) Pipe module settlement markers, (g) Battelle thermal conductivity probes, (h) Soil test moisture cells, (i) Copper-constantan thermocouples, (j) Thermistors, (k) Snow depth markers, (l) Thermal data acquisition system, 1. Resistance temperature detectors, 2. Heat flux transducers. Instructions on surveying profiles across pipe module berms are also included in this manual. Section "1" on the Thermal Data Acquisition System was written by Gas Arctic Systems.

Preliminary investigation of permafrost regression, Norman Wells test facility, Gas Arctic Project / **E.W. Brooker & Associates Ltd.** **Alberta Gas Trunk Line Company Limited** [Sponsor]
[S.l.] : Elmer W. Brooker & Assoc. Ltd., 1971.
7, 23 leaves : ill. (some folded) ; 30 cm.
ASTIS record 31818.
Languages: English
Libraries: ACU TJ930 .R47 NO.970
The Norman Wells test facility is set up to study possible thermal disturbances on permafrost due to pipeline construction. Instrumentation has been designed and fabricated in order to investigate factors related to permafrost thermal response as well as pipeline construction technique. A theoretical study regarding the thermal disturbance has been made. Methods of analysis have been programmed into computer codes. Soil investigations of the test site have been carried out and their results used to provide input data for the analysis. Verification of the theoretical work depends upon its prediction of the performance of the pipe line test loops. Measuring devices are to be installed to monitor performance. In order to investigate the validity of the instrumentation, it is imperative to study the predicted thermal response of the permafrost prior to the operation of the test facility. Four test modules have been set up, incorporating two types of construction (trench backfill and berm backfill) and two operating gas temperatures (15 degrees F and 65 degrees F). In this report, investigations of temperature regression have been made only for the hot-berm module. ... These investigations serve as design bases for instrumentation including, temperature sensors, thermal conductivity probes, settlement gauges, piezometers, density and moisture content gauges.

Norman Wells natural gas pipeline research facility : instrumentation : installation and initial performance / **PEMCAN Services (Pipeline Engineering and Management Services of Canada)** Gas Arctic Systems Study Group [Sponsor]
Calgary, Alta. : PEMCAN Services, 1972.
ca. 200 leaves : ill. (some col.) ; 29 cm.
ASTIS record 31869.
Languages: English

Libraries: ACU TJ930 .R47 NO.1129
This report describes the installation of instruments at the Norman Wells Research Facility. These instruments have been designed to measure the response of the permafrost subsurface to the construction and operation of a gas pipeline in six simulated configurations. A brief description of each instrument, of the soil properties to be measured and of the performance of the instruments to the end of December 1971, has been included. While the number of inoperative instruments is higher than anticipated, most of the remainder appear at this early stage to be functioning satisfactorily and show promise of providing the data required.

Norman Wells Natural Gas Pipeline Research Facility : evaluation of geotechnical data / **EBA Engineering Consultants Ltd.** **Canadian Arctic Gas Study Limited** [Sponsor]
Calgary, Alta. : EBA Engineering Consultants Ltd., 1974.
52, 30, 15, 29, [19] leaves : ill. (some folded) ; 29 cm.
ASTIS record 31819.
Languages: English
Libraries: ACU
The Norman Wells Natural Gas Pipeline Research facility was constructed in order to provide a source of quantitative data characteristic of construction and operation of a large diameter pipeline in permafrost regions. Instrumentation was installed to monitor behavior of the pipe and supporting soil. This report presents geotechnical data collected from vertical movement indicators, pore pressure transducers and nuclear moisture density access tubes. The data is evaluated with regard to tentative pipeline design application and the applicability of several theories pertaining to thawing soils are examined. ...Experimental surface coverings were found to retard the thaw significantly during the summer, however by fall thaw was continuing at the same rate under the shields whereas it had reduced significantly in other areas. The surface covering experiment was affected to a serious extent by two dimensional edge effects since the width of shield was not large relative to the depth of thaw. ...

Norman Wells natural gas pipeline research facility : site selection, instrumentation selection, test site construction / **Gas Arctic Systems Study Group**
[S.l.] : Gas Arctic Systems Study Group, 1972.
[50] leaves : ill. (some col.) ; 29 cm.
ASTIS record 31866.
Languages: English
Libraries: ACU
This report details the site selection, the construction of the test facility and the selection of associated instrumentation to monitor the thermal and geotechnical disturbances. Test site results will aid in the development and verification of a flexible computer analysis program for predicting the important elements of the pipe-soil interaction, and thereby allow the prediction of proper solutions to problems to be encountered along the entire proposed pipeline.

Norman Wells Natural Gas Pipeline Research Facility : subsurface conditions / PEMCAN Services (Pipeline Engineering and Management Services of Canada) Gas Arctic Systems Study Group [Sponsor]
[S.l.] : PEMCAN Services, 1972.
ca. 300 leaves : ill. ; 29 cm.
ASTIS record 31821.
Languages: English
Libraries: ACU TJ930 .R47 NO.967
This report describes the findings of an investigation of the subsurface conditions at the Norman Wells Research Facility, carried out at various times from April 13 to September 17, 1971. The soil and ice conditions encountered are presented in the form of field descriptions and classifications, laboratory test results, subsurface sections and photographs.

Thermal test facilities supplementary proposal for the Alberta Gas Trunk Line Company Limited / **PEMCAN Services (Pipeline Engineering and Management Services of Canada)** Alberta Gas Trunk Line Company Limited [Sponsor]
Calgary, Alta. : PEMCAN Services, 1971.
[43] leaves : ill. ; 29 cm.
ASTIS record 31867.
Languages: English
Libraries: ACU TJ930 .R47 NO.1131
This report presents PEMCAN's supplementary proposal to develop a test facility in the region of Norman Wells for the purpose of providing information for studies to be undertaken in the design and development of a natural gas pipeline from Prudhoe Bay, Alaska to Alberta. In undertaking thermal calculations, the factors that have an influence on the heat flow to and from the pipe include: climatic conditions, type of ground cover, topography, orientation of pipe line, type and condition of soil, mode on construction, and disturbance of adjacent terrain due to construction activities.

Norman Wells natural gas pipeline research facility : thermal data reduction and presentation procedures / **Canadian Arctic Gas Study Limited**
[S.l.] : Canadian Arctic Gas Study Ltd., 1973.
ca. 200 leaves : ill., ; 29 cm.
ASTIS record 31864.
Languages: English
Libraries: ACU TJ930 .R47 NO.1099
When Gas Arctic Systems made the decision to construct a Natural Gas Pipeline Research Facility at Norman Wells, N.W.T., it was recognized that as one of the major objectives was the collection of large quantities of thermal data, the reduction and presentation of those data in a form suitable for use by research scientists could be an onerous task. ... This report has been prepared to record the input parameters, equations, and analytic methods used in the reduction and presentation of thermal data. ...

Preliminary investigation of permafrost regression : Norman Wells test facility / E.W. Brooker & Associates Ltd. Arctic Systems Study Group [Sponsor] Alberta Gas Trunk Line Company Limited [Sponsor]
[Edmonton, Alta.] : E.W. Brooker Assoc. Ltd., 1971.
[33] leaves (15 folded) : ill. (some folded) ; 29 cm.
(Geotechnical report, no. 3)
Contains four folded drawings in map pocket.
ASTIS record 31697.
Languages: English
Libraries: ACU TJ930 .R47 NO.970
The Norman Wells test facility is set up to study possible thermal disturbances on permafrost due to pipeline construction. Instrumentation has been designed and fabricated in order to investigate factors related to permafrost thermal response as well as pipeline construction technique. A theoretical study regarding the thermal disturbance has been made. Methods of analysis have been programmed into computer codes. Soil investigations of the test site have been carried out and their results used to provide input data for the analysis. ... Four test modules have been set up, incorporating two types of construction (trench backfill and berm backfill) and two operating gas temperatures (15 degrees F and 65 degrees F). In this report, investigations of temperature regression have been made only for the hot-berm module. The other three are to be investigated and will be reported at a later date. These investigations serve as design bases for instrumentation including, temperature sensors, thermal conductivity probes, settlement gauges, piezometers, density and moisture content gauges.

Preliminary analyses of geotechnical data from Norman Wells test site : report no. 15 / **E.W. Brooker & Associates Ltd. Gas Arctic Systems Study Group [Sponsor]**
[Edmonton, Alta.] : E.W. Brooker Assoc. Ltd., 1972.
[24] leaves (2 folded) ; ill. (2 folded) ; 29 cm.
(Geotechnical report, no. 15)
ASTIS record 31708.
Languages: English
Libraries: ACU TJ930 .R47 NO.964
A preliminary analysis of the geotechnical data obtained from the Norman Wells Test Site has been undertaken. The purpose of this analysis is to assess the validity of applying the thaw consolidation theory (Morgenstern and Nixon 1971) to the case of a heated pipeline. ... The assumptions made in the formulation of the thaw consolidation theory are provided in the original publication, however, a review of the major assumptions used will be given here in order to establish the basis for this analysis. ... The theory applies to one-dimensional thaw consolidation. That is, heat flow and seepage occur in a vertical direction only. Furthermore, the heat source is assumed to be a step change in temperature of infinite extent applied at the surface. Clearly, the case of a heated pipeline does not meet these requirements. It is apparent, however, that these requirements are met reasonably well in the area immediately below the centre line of the pipeline. The analysis concentrates therefore on the conditions which develop directly below the pipeline. This simplified approach is felt to be valid since the behavior of the pipeline is dominantly affected by the conditions directly beneath it.

Gas Arctic Systems permafrost regression analysis : report no. 16 : Progress report for review meeting no. 8 / **E.W. Brooker & Associates Ltd.** **Gas Arctic Systems Study Group** [Sponsor]
[Edmonton, Alta.] : E.W. Brooker Assoc. Ltd., 1972.
[71] leaves : ill. ; 29 cm.
(Geotechnical report, no. 16)
ASTIS record 31709.
Languages: English
Libraries: ACU TJ930 .R47 NO.964
General progress of the geotechnical section of the Soil Behavior Study Group (April 18 to June 5, 1972) is discussed in this report. The report is organized as a series of independent brief report contributions by the various individuals involved at Brooker Associates, presented in Appendices A to G. These Appendices refer specifically to areas for further study as presented in the report on Review Meeting No. 7 by Dr. R.N. Yong. The text of this report summarizes the findings at these various areas of investigation and conclusions are drawn from them which will help direct future endeavors. ... Preliminary analysis of the geotechnical data obtained from the Norman Wells Test Site has been completed. The results are very encouraging (Appendix A) and indicate that for at least the first year of operation the idealized theory of thaw consolidation will provide realistic predictions. ...

**Developments and research on northern gas pipelines in Canada** / Walker, G.W.
Calgary, Alta. : Canadian Arctic Gas Study Ltd., 1973.
10 leaves : 3 ill. ; 28 cm.
Presented at the International Gas Union, World Gas Conference, 12th, Nice, France, June 1973
ASTIS record 30447.
Languages: English
Libraries: ACU **TJ930 .P62 W34 1973**
Considering the unique conditions of the Arctic, the large distance and large volumes of gas to be moved, several alternate modes in addition to the vapour phase gas pipeline for transportation of the Arctic gas to the Canadian and U.S. markets have been evaluated. These included: (1) Liquefaction of the gas and moving it to the markets as LNG by pipeline, railway and airplanes. (2) Conversion to methanol and moving it by pipeline. (3) "Dense Phase" gas pipelining at operating temperatures from 200 degrees K. (-100 degrees F.) to 166 degrees K. (-160 degrees F.) and pressures from 6.894 MN/sq m (1000 psi) to 13.788 MN/sq m (2000 psi). These investigations concluded that the conventional buried vapour phase gas pipeline has an economic advantage over any of the above-mentioned alternatives. Consequently the research work has been oriented toward the problems associated with the design, construction and operation of a large diameter, high pressure gas pipeline. It has further been found that since the northern half of the proposed pipeline will cross areas of permafrost soils, some of which become unstable when thawed, the flowing gas temperature should be maintained below the freezing point of water. Thus the research work was further oriented towards the problems associated with a chilled gas pipeline in the permafrost areas and included studies in the following

principal fields: (1) thermodynamics of gas flow (2) geotechnical and ground stability problems (3) surficial geology (4) ground temperature evaluation (5) protection of the environment (6) construction techniques (7) metallurgy. ... (Au)

# APPENDIX I

## Prudhoe Bay Test Facility

| **Test Facility** | **Prudhoe Bay Test Facility** |
|---|---|
| Location | Deadhorse, Alaska, USA |
| Owner | Gas Arctic Systems |
| Operator | Gas Arctic Systems |
| Participants | Gas Arctic Systems Study Group Members: Alberta Gas Trunk Line Company Ltd, Columbia Gas System, Northern Natural Gas Company, Texas Eastern Transmission Corporation, Canadian National Railway.<br>Pipe Line Technologists Inc. (Consultant)<br>Battelle Engineering (Engineering & Construction)<br>EW Brooker & Associates (Engineering) |
| Principal Researcher(s) | Battelle Engineering |
| Timing / Duration | 1971 – 1972 (major phase) |
| Purpose | Objective was to develop, by means of the design, construction and operation of an instrumented research facility, the information necessary for an engineering design to construct and operate a reliable gas pipeline through the far north with a minimum effect on the environment |
| Description of tests | Pipeline installed fully trenched and half-bermed in ice rich permafrost. Quoted cost $2million for construction, 1 yr operation & associated soil test program. |
| Test Components | 1, 48” pipeline loop incorporating half bermed burial with 18” and 30” cover on one leg, and fully trenched with 30” cover in the other leg. Trenched leg excavated by blasting and backfilled with natural soil, and by stitch drilling and excavation backfilled with gravel. 2 static (dormant) sections also installed, 120’ long, 4’ diameter capped at the ends, installed in buried and bermed conditions. |
| Operating Conditions | Pipeline operated nominally at 25$^{o}$F. |
| Instrumentation | Instrumentation included comprehensive arrays of thermocouples at 5 planes perpendicular to the pipe as well as away from the pipe to monitor undisturbed soil and the effect of construction. Heat flux transducers on the pipe surface, strain gauges in 2 directions to measure bending in both directions, and level poles attached to pipe & sleeved through soil. Static sections instrumented with thermocouples |
| Summary of results | Initial results showed bermed sections gave little temperature change over the first summer at 4’ depth |

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| | (construction disturbance was only 3') and temperatures dropped from October. Effects of thermal inertia near thaw pond giving higher moisture contents may explain differences observed between the different sections. Temperature for the trenched pipe was significantly higher at 12' depth in December than bermed sections, possibly due to the 8' construction disturbance. The zone of influence of soil temperature to the chilled pipe operation was limited to 6" to 12" in first 6 months. Near ground temperatures were warmer in the gravel section due to higher thermal conductivity of gravel. Ground temperature near the buried (trenched) pipe was never >32$^{o}$F, and no pipe movement measured. Temperature around the bermed section was >32$^{o}$F but the pipes were close to neutral buoyancy so no horizontal pipe movement measured. Vertical displacement from leveling & bending moments from strain gauges showed that most movement occurred during the simulated hydro test. The buried leg raised 1.5-2" at the NW corner during the hydrotest at 40$^{o}$F but no appreciable movement measured since. This is attributable to longitudinal thermal expansion of line being more pronounced on the buried portion and due to buoyancy effects. Further uplift was stopped by anchor strapping. Moments in the pipe were small compared to allowable values (2-3%). Average active layer depth across the site was 10". The bermed pipe sections depressed the permafrost table by 2-4". Bermed section showed the formation of a large cavity above the pipe, thought to be due to melting of ice and arching of the soil. |
| Faults, problems, shortcomings | Initial problems included drifting of temperature recording system due to changes in ambient temp in instrument room. Measurements were corrected by comparing to ice bath readings. Ice build-up of 0.5" on inside wall of pipes causing concern on heat transfer coefficients in the loop. Defrost cycles were incorporated into the operation procedure 1-3 times a week, removing 15-20 gallons of water each time. The problem was eliminated by October. Hydrostatic test simulation July 14-21 at 40$^{o}$F. Cold air flow started in July, but slow cool-down due to problems with refrigeration compressor – temp decreased to 27$^{o}$F in 10 days. Generator failure forced occasional shutdown. Dormant section floated out of the ground and extensive thaw settlement occurred over the chilled section during chilling shut-down. |

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|---|---|
| Requirements for further work | Some data on geothermal processes, heat flux and geotechnical properties. Value of data limited due to erratic operation due to power failures. Limited value for frost heave and thaw settlement analysis. |
| Reports | As listed. |
| Availability / access to data | ASTIS & AINA call references listed (with abstract) where available |

**Reference List:**

**Report on laboratory tests for thermal and engineering soil properties, Gas Arctic Systems Prudhoe Bay pipeline test site, Deadhorse, Alaska / R&M Engineering & Geological Consultants** Battelle Memorial Institute. Columbus Laboratories [Sponsor]
Fairbanks, Alaska : R&M Engineering & Geological Consultants, 1972.
37, 4, 11, 20, 9, 2, 42 leaves : ill. (some folded), 1 map ; 28 cm.
ASTIS record 31831.
Languages: English
Libraries: ACU
... The purpose of this report is to present: 1. An interpretation and description of general geologic and subsurface soil and ice conditions existing at the Prudhoe Bay test site. 2. The results of laboratory thermal conductivity tests performed on samples removed from the vicinity of the instrument planes. 3. Laboratory test results for all soil samples received from the test site. Part I of this report presents all general information and test results. Part II contains photographic logs of all core samples submitted from the second drilling program.

**Report on subsurface soil investigations, Gas Arctic Systems Prudhoe Bay pipeline test site, Deadhorse, Alaska, part III / R&M Engineering & Geological Consultants** Battelle Memorial Institute. Columbus Laboratories [Sponsor]
Fairbanks, Alaska : R&M Engineering & Geological Consultants, 1972.
5, [6] leaves : ill. (1 folded) ; 28 cm.
ASTIS record 31832.
Languages: English
Libraries: ACU **TJ930 .R47**NO.1119
As a part of Gas Arctic Systems tests of the performance of a large diameter gas pipeline under various soil and climatic conditions, a test facility was constructed at Deadhorse near Prudhoe Bay on the Alaskan Arctic Coastal Plain. This facility has been described in detail in Part I of this series of reports and the reader is referred to this earlier submittal if more details are required. Previously, two separate subsurface investigations had been performed at the test site. The first program consisted of five, six inch diameter test holes drilled at the southwest corner of the test loop. The second program consisted of five, 36 inch diameter test holes, one at each of the instrument planes and one near the reference plane. It was determined that more information was needed in order to enable accurate subsurface profiles to be constructed at the instrument planes. The purpose of this study was to provide the information necessary to construct the needed profiles.

**Developments and research on northern gas pipelines in Canada** / Walker, G.W.
Calgary, Alta. : Canadian Arctic Gas Study Ltd., 1973.
10 leaves : 3 ill. ; 28 cm.
Presented at the International Gas Union, World Gas Conference, 12th, Nice, France, June 1973
ASTIS record 30447.
Languages: English
Libraries: ACU **TJ930 .P62 W34 1973**
Considering the unique conditions of the Arctic, the large distance and large volumes of gas to be moved, several alternate modes in addition to the vapour phase gas pipeline for transportation of the Arctic gas to the Canadian and U.S. markets have been evaluated. These included: (1) Liquefaction of the gas and moving it to the markets as LNG by pipeline, railway and airplanes. (2) Conversion to methanol and moving it by pipeline. (3) "Dense Phase" gas pipelining at operating temperatures from 200 degrees K. (-100 degrees F.) to 166 degrees K. (-160 degrees F.) and pressures from 6.894 MN/sq m (1000 psi) to 13.788 MN/sq m (2000 psi). These investigations concluded that the conventional buried vapour phase gas pipeline has an economic advantage over any of the above-mentioned alternatives. Consequently the research work has been oriented toward the problems associated with the design, construction and operation of a large diameter, high pressure gas pipeline. It has further been found that since the northern half of the proposed pipeline will cross areas of permafrost soils, some of which become unstable when thawed, the flowing gas temperature should be maintained below the freezing point of water. Thus the research work was further oriented towards the problems associated with a chilled gas pipeline in the permafrost areas and included studies in the following principal fields: (1) thermodynamics of gas flow (2) geotechnical and ground stability problems (3) surficial geology (4) ground temperature evaluation (5) protection of the environment (6) construction techniques (7) metallurgy. ... (Au)

Engineering Design and Construction of a Gas Pipeline Research Facility at Prudhoe Bay, Alaska. Battelle Engineering May 1972 TJ930.P62.R4647. 1972 C1

Completion Report, Prudhoe Bay Test Facility, Pipe Line Technologists Inc. August 1971. TJ 930. R47. No 1317 & 1318.

Engineering and Environmental Factors related to the Design, Construction and Operation of a Natural Gas Pipeline in the Actic Region (Based on the Prudhoe Bay, Alaska, Research Facility), Battelle Columbus Laboratories. Final Report. March 1974. Vols I – IV + Supplementary Report on Latent Berm Effects.

# APPENDIX J

## Quill Creek Test Facility

| Test Facility | Quill Creek Test Facility |
|---|---|
| Location | Yukon Territory, 165km SE of Alaska border |
| Owner | Foothills Pipe Lines (Yukon) |
| Operator | Foothills Pipe Lines (Yukon) |
| Participants | Alberta Gas Trunkline Limited (AGTL)<br>West Coast Transmission |
| Principal Researcher(s) | J. R. Ellwood, D. E. Fielder, L. E. Carlson |
| Timing / Duration | 1981 - |
| Purpose | The purposes of test site were (1) to study construction methods for the installation of large diameter pipelines in permafrost, (2) to observe the effectiveness of mitigative designs in minimizing thaw settlement, (3) to study the behaviour of cuts in ice rich hills, and (4) to provide data on the thermal behaviour of design modes for comparison with thermal model predictions. |
| Description of tests | Activities included (1) sidehill grading with various methods of protecting & stabilizing cuts in ice rich hills, (2) disposal area for storage of ice rich soils from sidehill cuts, (3) buoyancy control using granular fill as pipeline buoyancy control, (4) permafrost mitigative design construction for warm pipeline operation. |
| Test Components | Pipe sections placed on a 1m thick gravel pad, with 100mm polystyrene insulation embedded 300mm from the base. Pipeline laid on the gravel pad and covered with gravel or concrete segments to protect against low ambient temperature, damage & restrain against movements due to temperature & pressure. 3 pipe sections covered by gravel with zero, 100mm & 200mm urethane insulation coating. 2 sections covered in concrete segments including urethane insulation in saddle. |
| Operating Conditions | All pipes maintained at +15$^{o}$C by air heating system. |
| Instrumentation | Matrix of thermisters placed within & below gravel pads to record frost line. |
| Summary of results | Uninsulated pipe in gravel showed growth of the thaw bulb under the pipe, with the warm pipe preventing seasonal freezing of the gravel and soil below. Analysis suggests continued growth of thaw bulb would occur longterm. Insulated pipes show complete thawing of the gravel during summer and complete refreeze during winter. Concrete sections constructed in summer using |

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| | warm gravel pads over the 0.5m thick thawed active layer increased thaw to 2m due to construction. 1 year of operation shows the thaw depth approximately constant with active layer not quite refrozen. Thermal analysis agrees well with measurements of 0°C isotherm. Measured settlements approximately 160mm after 22 months in the gravel sections (insulated & noninsulated) and 50mm in concrete sections after 16 months (later start date). Attributed to consolidation of small amounts of seasonal thawing due embankment placement. This correlates with an unheated pipe section which showed similar settlement. Concrete section showed less settlement due to installation in summer and consolidation occurring before startup and monitoring. Sidehill cut tests showed that use of mesh & jute covering could stabilize cut slopes in ice rich soils. |
| Faults, problems, shortcomings | |
| Requirements for further work | Data could be used for thaw settlement data and geothermal modeling |
| Reports | As listed. Very little data in the public domain |
| Availability / access to data | ASTIS & AINA call references listed (with abstract) where available |

**Reference List:**

Testing pipelining techniques in warm permafrost / **Carlson, L.E.** **Butterwick, D.E.**
In: Permafrost : Fourth International Conference, proceedings, July 17-22, 1983. - Washington, D.C. : National Academy Press, 1983, p. 97-102, figures, table
ASTIS record 14550.
Languages: English
Libraries: ACU 6B441.I562 4th 1983
A thaw settlement research facility was built by Foothills Pipe Lines (Yukon) Ltd. as part of the permafrost engineering design for the Alaska Highway Gas Pipeline Project. The main purposes of the test facility were (1) to study construction methods for the installation of large diameter pipelines in permafrost, (2) to observe the effectiveness of mitigative designs in minimizing thaw settlement of the pipe and right-of-way surface, (3) to study the behavior of cuts in ice rich hills, and (4) to provide data on the thermal behavior of design modes for comparison with thermal model predictions. This paper discusses the observations of the pipeline design performance and the comparison of that performance with initial predictions.

**Frost Heave and Thaw Settlement Test Facilities** / Carlson, L. E.
Pipelines and Frost heave. 1985. Proceedings of a Conference, Caen, France. Sponsored by Energy, Mines and Resources, Canada and Ministère de l'Urbanisme et du Logement, France. 75 pp. Carleton University, Ottawa, Canada.