Final Report

Feasibility of Buried Flow Lines in Permafrost

Prepared for

Conoco Inc.
Anchorage, Alaska

March 1989

87A111C

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Steve Rossberg
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3201 "C" Street, Suite 200
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Dear Steve:

Feasibility of Buried Flow Lines in Permafrost

Transmitted herewith are four copies of our final report on "Feasibility of Buried Flow Lines in Permafrost." This version of the report addresses comments received from Conoco on a draft of the report which was issued in June 1987. We have enjoyed working with you on this study.

Very truly yours,

Howard P. Thomas, P.E.
Project Manager

HPT/jj
93/47

Enclosure

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FEASIBILITY OF BURIED FLOW LINES
IN PERMAFROST

INTRODUCTION

We understand that Conoco plans to connect drill pads B and D at Milne Point with flow lines to carry crude oil and injection water. As depicted on Figure 1 attached, a mile-long gravel road, constructed approximately ten years ago, currently connects the two drill pads. The road cross-section is nominally 4 ft thick, 30 ft wide at the crest, and with 3:1 side slopes, although we understand it is planned to raise the road by at least 6 in.

Pipelines tentatively planned for the development are as follows:

	Diam. (in.)	Wall Thickness (in.)	Grade
Oil (2)	4	0.237	Std.
Future Injection Water Line	6	0.718	XSS

Two operating scenarios are being considered. The first is the immediate flow stream with two wells pumping and combined flow rates of 1000 BPD of oil and 500 BPD of water. Under this scenario, the injection water line would not yet be used. The produced oil and water would be pumped through the two 4-in.-diam lines, one of which will be used as a test line.

The second operating scenario corresponds to the long-term potential development of wells in the area, namely a tripling of the above flow rates for oil and water and pumping of 6000 BPD of fresh injection water. Under this scenario, a 6-in.-diam water injection line will be installed and possibly an additional 4-in. line.

Maximum expected operating temperatures are 100°F for the oil lines and 80°F for the injection water line. Tie-in temperature corresponding to summer tie-in is about 40°F.

The usual practice on the North Slope which has evolved over the past 14 years is to elevate flow lines. This decouples the lines thermally from the underlying frozen permafrost ground and provides ready maintenance access to them. However, it also adds an increment of cost, primarily for the necessary structural supports (VSM's and crossbeams) but also because expansion loops must be provided in an unrestrained system. For the small-diameter lines and relatively-low flow rates planned by Conoco, it may be feasible to insulate the lines and bury them in the existing road or adjacent to the road. The purpose of the present study was to evaluate the feasibility of the buried mode for the planned flow lines.

This report outlines our approach to the study, describes results of interviews conducted and literature reviewed, general site conditions, insulation considerations, touches on several practical aspects, and summarizes our conclusions and recommendations.

APPROACH

Our approach to this initial feasibility-level evaluation was as follows. First of all, we conducted a brief review of available literature on pipelines in permafrost, thawing and thaw settlement, insulation systems and the like. Then, we interviewed several knowledgeable oil industry engineers to obtain their ideas on possible configurations for a buried flow line system. We also made a brief review of available aerial photography and subsurface information for the Milne Point area.

Following this, we developed two promising configurations for the buried piping considering thawing, thaw settlement, traffic loading and accessibility. This effort included estimating required insulation thickness, identification of likely design requirements, and development of recommendations for design criteria development.

LITERATURE REVIEW

Papers reviewed are listed at the end of this report. In addition, U.S. Patent 4,181,448 dated January 1, 1980, assigned to the Atlantic Richfield Company and entitled "Combination Roadway and Pipeline Way in Permafrost Regions" was identified and reviewed. (A copy of this patent is attached hereto as Appendix A.) The following paragraphs briefly describe (1) the Alyeska fuel gasline, and (2) buried pipelines used in the Prudhoe Bay Waterflood project.

Constructed during the winter of 1976/77, the Alyeska fuel gas line extends 147 miles from Pump Station 1 to Pump Station 4. Consisting of uninsulated 8- and 10-inch steel pipe, the fuel gas line was constructed in the buried mode parallel to the Alyeska Haul Road (now called the "Dalton Highway"). The line was constructed off a snow workpad at a typical distance of 15 ft from the toe of the roadway fill slope. The ditch for the line was typically excavated in the frozen ground using a piece of equipment called a "Roc Saw." This resulted in a vertical-sided ditch 18 in. wide and a depth of cover over the pipe of about 36 in. Backfilling of the pipe was done with select (gravel) material, except that 4 in. of styrofoam board insulation were placed above the pipe at a depth of 12 to 15 in. below the original ground surface.

Alyeska's fuel gas line is basically an ambient line with the gas taking on the temperature of the ground through which it passes. Settlement tolerances for a gas line are greater than for an oil line as the environmental consequences of a gas leak are less severe than those of an oil leak. Apart from some localized thermal erosion and associated ground surface disturbance and development of one or two sags which have required pipe lifts, Alyeska did not experience any major problems with the fuel gas line during its first decade of operations.

In 1982, several buried pipelines were designed and constructed by ARCO Alaska, Inc. in the 2.5-mile-long Waterflood Causeway at Prudhoe

Bay. The lines consisted of two seawater supply lines (40 and 36 in. diameter) and a 10-3/4-in. gas feeder line. The lines were placed in conjunction with a widening and raising of the pre-existing gravel causeway (see attached figures). A minimum of 3.3 ft of cover was provided over the lines and the lines were designed for superimposed traffic loading due to loaded gravel hauling trucks and heavy crawler-supported modules.

INTERVIEWS

Three oil-industry engineers with extensive North Slope design experience were interviewed and results of the interviews are summarized in the following paragraphs.

Interviewee A, an engineer with Exxon Production Research Company, felt that burial of small-diameter flow lines would be technically feasible but may or may not be economically feasible. The reason for this is that there are numerous insulation systems, many of which are expensive and all of which have their drawbacks (moisture penetration through joints, etc.). He favored a scheme similar to that depicted in Figure 2 in the ARCO patent (place styrofoam board stock adjacent to the road fill, lay the flow lines on this, extend the road shoulder out over the lines), except that he said he would also insulate the oil lines by placing jacketed polyurethane on them. If possible, he said he would keep the piping above the water table.

Interviewee B, an engineer with ARCO Alaska, Inc., also suggested placing the lines at the toe of the existing road fill, except that, instead of burying them, he said he would support the lines on timber sleepers providing a 1-ft air space beneath the flow lines. This air space would effectively decouple the lines thermally from the ground such that only conventional aboveground insulation would be required on the piping. However, for this scheme, the piping would be unrestrained and would need anchors and expansion loops, perhaps every 1200 ft. Interviewee B said this approach was used successfully for the Lisburne Waterflood seawater pipeline. He recommended that temperature profiles be estimated along the piping, that this might show that, beyond a certain burial length, the oil temperature may drop to ambient. (Significance of this is that, for the buried mode, only the initial portion of the line would then need to be insulated.) For buried insulation, Interviewee B favored 4 in. of styrofoam board stock beneath the flow lines.

Interviewee C, an engineer with Alyeska Pipeline Service Company, recommended that, to reduce costs, Conoco consider using HDPE (High-Density Polyethylene) pipe for all low-pressure lines. Alternately, he recommended consideration be given to developing a prefabricated jacketed and insulated pipe bundle to contain all three lines (perhaps in 100-ft lengths). Buried piping at the Alyeska pump stations and terminal consisted of jacketed closed-cell polyurethane with 3.5-pcf density and 150-mil UV-stabilized jacket. Biggest problem with this system, which has required considerable maintenance, has been (1) the insulation becomes water-saturated, which greatly reduces its thermal efficiency, and (2) observed accelerated corrosion of the steel.

SITE CONDITIONS

WCC conducted a brief review of ground/permafrost conditions along the road connecting Pad B to Pad D as a part of this study. Our review of available information sources included a report on air-photo analysis and landform soil properties along the Trans-Alaska Pipeline System by the State of Alaska Division of Geological and Geophysical Surveys; the December 1983 Milne Point Project Geotechnical Report which included information from boring logs and laboratory tests, and a review of available black and white airphotos of the project area, scale 1 inch = 500 ft, taken on 8/26/83.

The Milne Point area is typical of the Arctic Coastal Plain, being transected by north-flowing streams separated by interfluves with very little relief. The most widespread features on the interfluves are the prominent thaw lakes which have a north-northwest orientation.

Soil stratigraphy in the area is limited to three distinct layers which vary substantially in thickness. A surficial, low-density, ice-rich organic soil layer ranges from 0 to 6.5 ft, with a median thickness of 2.5 ft. Underlying the organics is an ice-rich, silty fine sand, SM or SP-SM. The bottom of this low-density silty sand layer ranges from 8 ft to 26 ft in depth with a median depth of 17.5 ft. Below the silty sand is a dense gravelly sand, SW or GW, extending to a depth of 50 ft or more.

The two upper units are ice-rich, of low density, and are not thaw stable. The coarse lower unit is generally thaw stable and not ice-rich although excess ice does occur. All the soils are permanently frozen except for an active layer extending to a depth of 1 to 1.5 ft in undisturbed areas, 2 ft deep in areas with polygons, and about 3.5 ft where the ground surface has been disturbed. Massive ice lenses were encountered in the upper two soil units.

The airphotos show that the road traverses areas of polygons, portions of thaw lakes and former thaw lakes. Some recent ponding has been caused by localized blocking of drainage. Thermokarst settlement has likely resulted from the ponding. It appears that minor settlement has also occurred where the margins of the thaw lakes are adjacent to the road embankment. The ice-wedges at the borders of polygons intersected by the road also show signs of minor thermal degradation.

Due to the high content of segregated ice and massive ice in the upper two soil units, buried warm pipelines will require an insulation design that will prevent thermal degradation. The present road embankment is a relatively-thin overlay which may have allowed some thawing to occur beneath it. The extent of thawing under this embankment needs to be identified and evaluated prior to burying a pipeline within the road. The greatest potential for settlement is where the pipeline alignment intersects ice wedges and shallow massive ice lenses.

In summary, according to the December 1983 Project Geotechnical Report, basic stratigraphy in the project area is relatively uniform and consists of continuous permafrost comprised of a layer of ice-rich silty sand overlying an ice-poor gravelly sand. The silty sand layer increases in thickness from Pad D where it is 7 to 12 ft thick to Pad B where it is about 18 ft thick. With massive ice in the form of wedges and lenses, the silty sand has a representative thaw strain of 18%. Not quite thaw stable, the gravelly sand has a representative thaw strain of 5%. Mean annual ground temperature in the area is about 15°F.

INSULATION CONSIDERATIONS

As the upper frozen silty sand is ice rich and needs to be thermally protected, insulation will be needed to limit heat flow from the warm pipelines to the permafrost. This insulation could either be foam insulation on the pipelines themselves or board stock insulation placed beneath the pipelines, or both. In addition, at least a nominal thickness of insulation will be needed on the pipelines themselves to prevent congealing of the contained crude oil or freezing of injection water in the event of a late-winter shutdown. Alternatively, heat tracing could be placed on the piping for this contingency.

A few calls to vendors were made as part of this study. Foam Sales and Marketing of Sun Valley, California, sells polystyrene foam in 4 by by 8 ft sheets with thicknesses of 1 to 12 in. For a 1-lb density and a minimum order of 300,000 board feet, 1987 Seattle price was 12¢/board foot. Assuming a 4 in. thickness to be required, to be provided with overlapped 2-in.-thick sheets, if one sheet is placed lengthwise on the fill slope and two sheets are placed flat at the toe, this gives a cost per mile for this insulation of about $30,000 plus freight.

For pipe insulation, the optimal system appears to be sandwich construction consisting of steel pipe surrounded by foamed-in-place urethane, coated with a waterproof polyurethane coating. Weld joints must be made up in the field with a chemically-generic system. An example of a two-component elastomer coating is Terra-Thane 500, which is manufactured by United Coatings, Inc. and supplied in Alaska by GeoCHEM, Inc.

The thickness of insulation required is normally calculated as that needed to prevent thawing from extending below the base of the roadway embankment. For convenience, a calculation procedure from the Milne Pt. project design documentation is presented in Appendix B to this report.

PRACTICAL ASPECTS

A sufficiently thick layer of gravel placed on the ground surface on the North Slope will result in aggradation rather than degradation of the permafrost (see Figure 2). However, a 4-ft thickness does not quite replace the insulating effect of the original active layer and it appears that the resulting progressive thawing is the cause of the ponding which has been observed along the road from B Pad to D Pad.

Based on initial cost, it appears that support of the lines on timber sleepers at the toe of the road embankment would be the least expensive alternative. However, these would be vulnerable to damage (e.g., due to vehicles running off the road in whiteouts) and they would also pose an obstruction to passage of caribou.

As a point in favor of burial, small-diameter lines have significantly greater flexibility and resistance to ovalling than large-diameter lines.

As prevailing winds are from the west, snow tends to drift along the eastern edge of the roadway embankment. In addition to this, installation of a guard rail to protect the pipelines can be expected to cause additional drifting of snow on the downwind side of the guard rail.

It would be undesirable for the oil temperature to drop to the ambient ground temperature. However, natural friction heating will probably prevent this from occurring as long as the pipelines are operating. It appears that some insulation or heat tracing will be needed on the piping for winter shutdowns.

The biggest problem with use of urethane as belowground pipe insulation is saturation and attendant loss of thermal effectiveness as a result of penetration of water.

The greatest anticipated traffic loads on the buried piping will result from moving drill rigs. For example, the Nabors 27E wheeled rig weighs on the order of 1 to 2 million pounds. A general procedure for evaluating effects of superimposed traffic loads on buried piping has been developed and presented by Thomas and Manikian (1985).

Bundling of lines, although it is attractive as a concept, does not appear to be amenable to the phased construction envisioned by Conoco.

CONCLUSIONS

Based on the foregoing discussion, burial of small-diameter flow lines with relatively low flow rates at Milne Point appears to be feasible.

Along the existing gravel road between Drill Pads B and D, subsoils consist of continuous permafrost which has apparently experienced some surface thawing as a result of the thin gravel overlay and some ponding of drainage. The upper frozen silty sand is ice-rich and needs to be protected thermally. This will require insulation.

Figure 3 shows two apparently-feasible alternative configurations for the buried pipelines. Alternative A consists of a 9-ft widening of the roadway, followed by excavation of a 3-ft deep trench 2 ft wide for the buried piping. The piping would be well insulated to prevent additional subgrade thawing and a minimum 1 ft of cover would be provided. In addition, a guard rail would be provided to keep traffic off the pipelines. Drawbacks of this scheme include (1) excavation could be difficult if the embankment is frozen, (2) sidewalls could cave in if the embankment is thawed, and (3) the bottom of the excavation could be at or near the water table.

Similar to the concept presented in the ARCO patent, Alternative B consists of constructing a small gravel berm at the toe of the present embankment, placing styrofoam board stock on the berm and up the slope, laying the pipelines as shown with a limited thickness of surrounding insulation or heat tracing, and then widening the roadway by 6 ft, thereby burying the pipelines.

RECOMMENDATIONS

The following recommendations appear to be appropriate in light of the above discussion and conclusions.

- To avoid drifting snow, it will be best to keep the pipelines on the west side of the roadway.
- Several exploratory borings should be drilled along the alignment, including installation of thermistor strings, to check present thermal regime (extent of thawing) and subsurface conditions.
- A thermal analysis should be conducted to determine required insulation thicknesses. First of all, a one-dimensional analysis should be conducted to obtain a profile of operating temperature along the lines. Then, a two-dimensional analysis should be conducted, transverse to the pipelines, modelling thawing in and beneath the embankment.
- Detailed costing needs to be done to see which of the two proposed alternatives is more cost-effective.

- At least 2 ft of cover needs to be provided if there will be traffic over the pipelines.

- Consider installing culverts in areas of ponded drainage.

- To save on costs, consider using HDPE pipe for low-pressure lines.

- Monitor the pipelines after they are installed, especially in thermokarst areas.

REFERENCES

Airphotos of Milne Point Area: Black and white, 1 inch = 500 ft, by Air Photo Tech, Inc., taken on 8/26/83, RD. 7 Nos. 1-5.

Anonymous (1977), "264 Miles of Pipe Gather Prudhoe Bay Oil and Gas." Pipe Line Industry, August.

Bock, G.R. (1979), "Arctic Winter Construction and Cost Estimating of the North Slope Fuel Gas Pipeline," Proceedings of ASCE Specialty Conference on Pipelines in Adverse Environments.

Carlson, G.L. and Cheap, G.C. (1978), "Innovations Met Trans-Alaska Line Insulation Requirements," The Oil and Gas Journal, February 27.

Esch, D.C. (1978), "Road Embankment Design Alternatives over Permafrost," Proceedings of ASCE Cold Regions Specialty Conference.

Ewing, R.C. (1974), "Closed-cell Polyurethane Foam Insulates North Slope Pipelines," The Oil and Gas Journal, July 8.

Ferrians, O.J. et al (1969), "Permafrost and Related Engineering Problems in Alaska," USGS Professional Paper 678.

Geotec Services, Inc. (1983), Geotechnical Criteria and Design Basis for Milne Point Project, prepared for Continental Pipeline Company.

Hale, D. (1975), "Special Insulated Pipe System Developed for Trans-Alaska Pipeline," Pipeline and Gas Journal, August.

Heuer, C.E. et al (1983), "Design of Buried Seafloor Pipelines for Permafrost Thaw Settlement," Proceedings of Fourth International Conference on Permafrost.

Hwang, C.T. et al (1980), "Thermal Design for Insulated Pipes," Canadian Geotechnical Journal, Vol. 17, No. 4.

Jahns, H.O. et al (1973), "Permafrost Protection for Pipelines," Proceedings of Second International Permafrost Conference.

Kreig, R.A. and Reger, R.D. (1982), Airphoto Analysis and Summary of Landform Soil Properties Along the Route of the Trans-Alaska Pipeline System, Geologic Report 66, State of Alaska Division of Geological and Geophysical Surveys.

Nelson, R.A. et al (1983), "Thaw Strain Data and Thaw Settlement Predictions for Alaskan Soils," Proceedings of Fourth International Conference on Permafrost.

Nyman, K.J. (1983), "Thaw Settlement Analysis for Buried Pipelines in Permafrost," Proceedings of the Conference on Pipelines in Adverse Environments II, ASCE.

Palmer, A.C. (1972), "Settlement of Pipeline on Thawing Permafrost," Transportation Engineering Journal, ASCE, August.

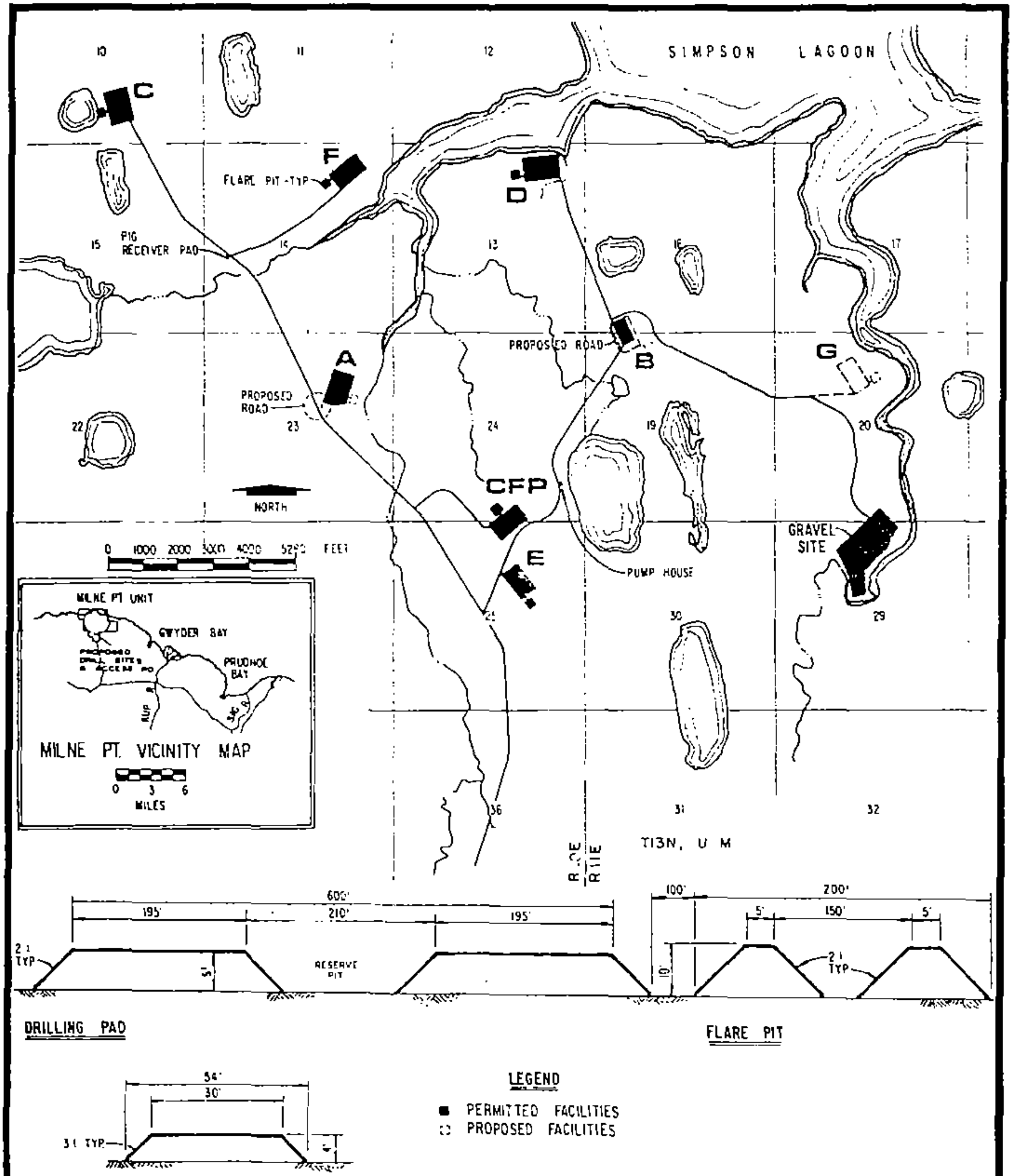
Speer, T.L. et al (1973), "Effects of Ground-Ice Variability and Resulting Thaw Settlement on Buried Warm-Oil Pipelines," Proceedings of Second International Permafrost Conference.

Thomas, H.P. and Manikian, V. (1985), "Effects of External Loadings on Large-Diameter Buried Pipelines," Proceedings of the Specialty Conference, "Arctic '85." ASCE.

Thomas, H.P. and Tart, R.G. (1984), "Two-Dimensional Simulation of Freezing and Thawing in Soils," Proceedings of the Third International Specialty Conference on Cold Regions Engineering, ASCE.

Weidler, J.V. et al (1985), "Technical Considerations for Beaufort Sea Pipelines," Proceedings of the Specialty Conference, "Arctic '85," ASCE.

Wellman, J.H. et al (1976), "Design and Construction of Synthetically Insulated Gravel Pads in the Alaskan Arctic," Proceedings of Second International Symposium on Cold Regions Engineering, Fairbanks, Alaska.



SITE PLAN

KUPARUK FIELD
NORTH SLOPE BOROUGH
STATE OF ALASKA

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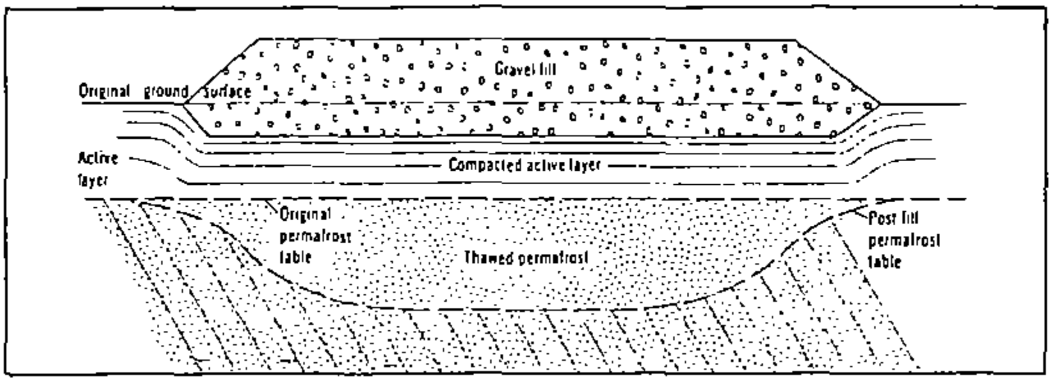
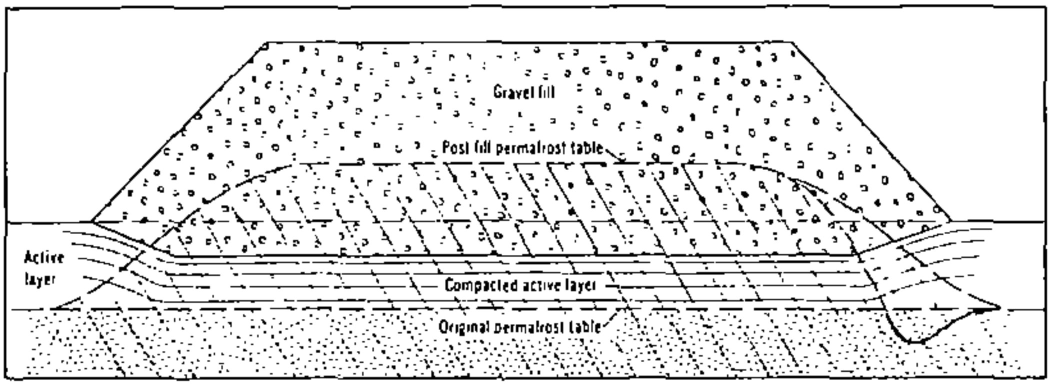
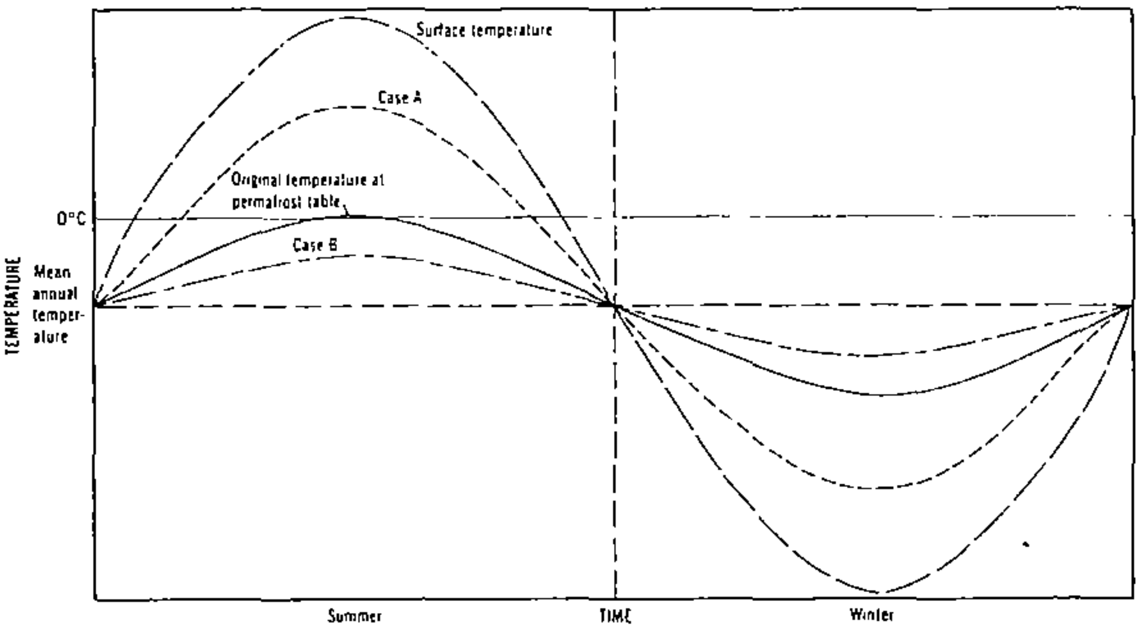
Figure 1



A. Effect on permafrost table if insulating of fill plus compacted active layer is less than the insulating effects of original active layer



B. Effect on permafrost table if insulating effect of fill and active layer is greater than the insulating effect of the original active layer.



C. Effects of cases *A* and *B* on amplitude of seasonal temperature variation at original permafrost table.

From Ferrians (1969)

EFFECT OF GRAVEL FILL UPON THERMAL REGIME

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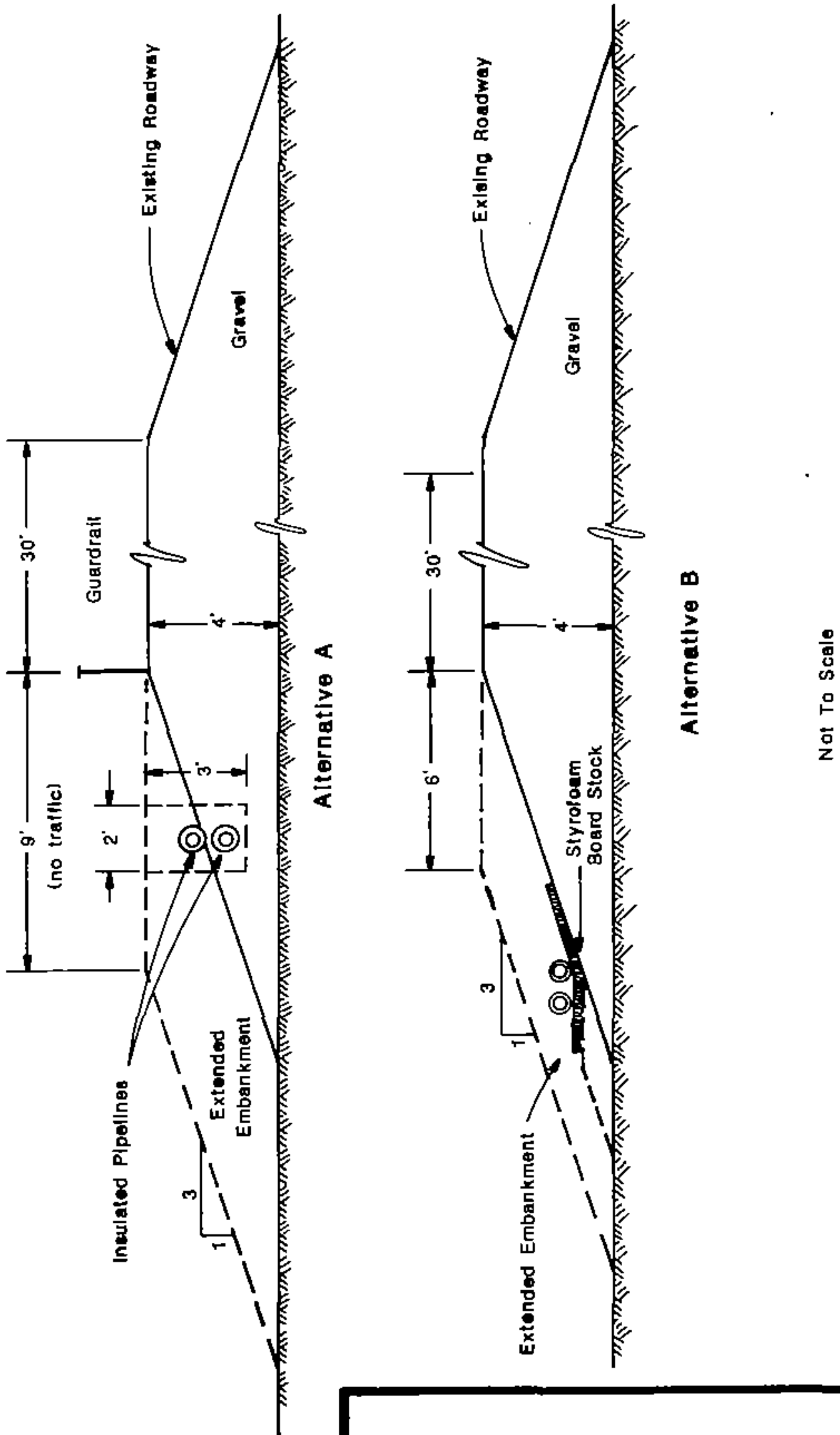
Figure 2



CONCEPTUAL
ROADWAY CROSS-SECTIONS

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Figure 3

Appendix A

ARCO Patent

United States Patent [19]

Crosky

[11] **4,181,448**

[45] **Jan. 1, 1980**

[54] **COMBINATION ROADWAY AND PIPELINE WAY IN PERMAFROST REGIONS**

[75] Inventor: Robert A. Crosky, Anchorage, Ala.

[73] Assignee: Atlantic Richfield Company, Los Angeles, Calif.

[21] Appl. No.: 945,672

[22] Filed: Sep. 25, 1978

[51] Int. Cl.² E01C 3/00

[52] U.S. Cl. 404/27; 404/3

[58] Field of Search 404/3, 2, 1, 27, 17, 404/18, 72, 71, 28

[56] **References Cited**

U.S. PATENT DOCUMENTS

245,721	8/1881	Henning	404/2
358,778	3/1887	Holt	404/3
744,878	11/1903	Sayre	404/27
2,082,429	6/1937	Sterns	404/2
2,420,833	5/1947	Monroe	404/28 X
3,272,096	9/1966	Lum	404/3 X
3,279,334	10/1966	Quartararo	404/31
3,503,425	3/1970	Holm	404/3 X
3,626,702	12/1971	Monahan	404/28 X
3,839,518	10/1974	Rubens	404/27 X
3,880,538	4/1975	Burt	404/28

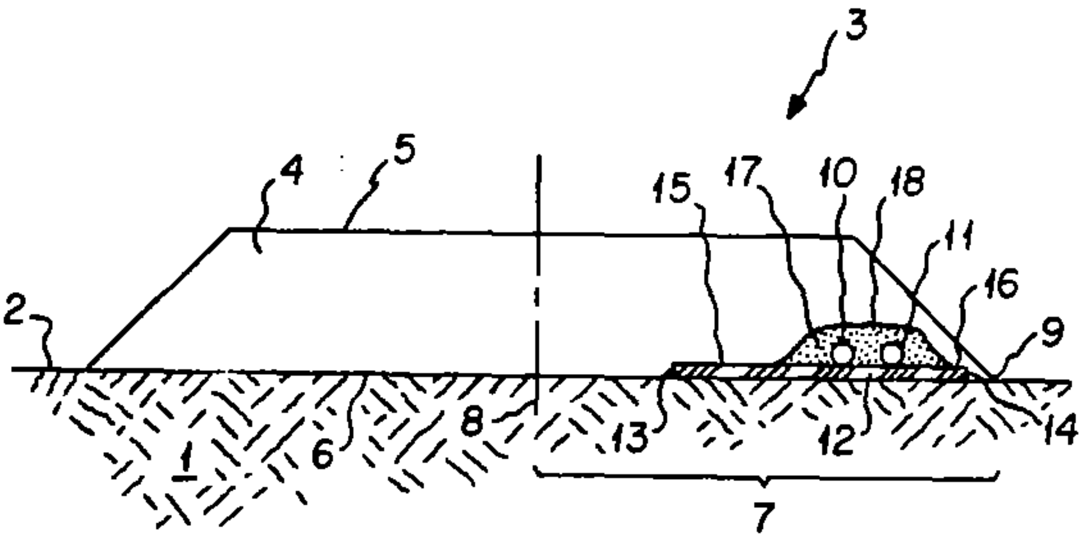
Primary Examiner—Nile C. Byers, Jr.

Attorney, Agent, or Firm—Roderick W. MacDonald

[57] **ABSTRACT**

A combination roadway and pipeline way for use over permafrost comprising a roadbed and at least one pipeline embedded in a side area of the roadbed, insulation means carried between the pipeline and permafrost and extending laterally from both sides of the pipeline a distance sufficient to prevent substantial amounts of heat radiation from passing from the pipeline around the edges of the insulation means and into the permafrost.

9 Claims, 2 Drawing Figures



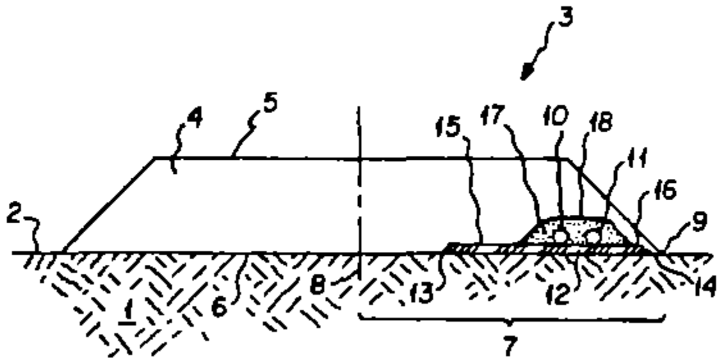


FIG. 1

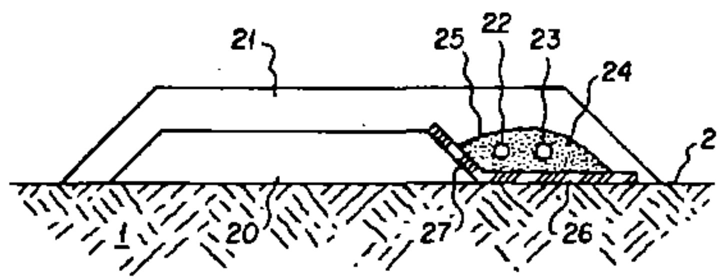


FIG. 2

COMBINATION ROADWAY AND PIPELINE WAY IN PERMAFROST REGIONS

BACKGROUND OF THE INVENTION

Heretofore in laying pipelines over permafrost regions, in order to prevent melting the permafrost by heat transfer from the pipeline, the pipeline have been either elevated in the air or buried in the permafrost and cooled by artificial means.

Although supporting pipelines over permafrost, or providing permafrost cooling by artificial means in the buried case, is very good for maintaining the permafrost frozen even in summer months, it can be desirable in some situations for aesthetic, environmental, or even operational purposes to have the pipeline buried in roadways or berms constructed for this purpose.

SUMMARY OF THE INVENTION

According to this invention, one or more pipelines can be essentially buried yet without disturbing or thawing the underlying permafrost, even in summer.

Accordingly, it is an object of this invention to provide a new and improved method for laying pipelines in permafrost regions.

Other aspects, objects and advantages of this invention will be apparent to those skilled in the art from this disclosure and the appended claims.

BRIEF DESCRIPTION OF THE DRAWING

FIG. 1 shows a cross-sectional view of the combination roadway and pipeline way of this invention.

FIG. 2 shows a cross-sectional view of the combination roadway and pipeline way of this invention when built over a prior existing roadbed.

DETAILED DESCRIPTION OF THE INVENTION

More specifically, FIG. 1 shows permafrost 1 whose upper surface 2 has a combination roadway and pipeline way 3 thereon. Roadway 4 is a trapezoidal shaped pile of material such as gravel or any other desired roadway construction material with an upper travel surface 5 and bottom surface 6 which contacts the surface 2 of permafrost 1. Side area 7 of the roadway, which side area can extend from the center 8 of the roadway to the outer edge 9 of the roadway, but preferably is closer to outer edge 9 than center 8, carries embedded therein at least one pipeline shown in FIG. 1 as two separate pipelines 10 and 11.

Roadbed 4 is longitudinally extending as are all roads and, similarly, pipelines 10 and 11 are also longitudinally extending and are essentially longitudinally parallel to the longitudinal axis of roadbed 4. Longitudinally extending insulation means 12, with its longitudinal edges 13 and 14, is carried in roadbed 4 and between the underside of pipelines 10 and 11 and the upper surface 2 of permafrost 1. Edges 13 and 14 are laterally displaced beyond the outer sides of pipelines 10 and 11 by distances 15 and 16, respectively. Distances 15 and 16 are sufficient in length (based on the dimensions of the materials and other physical characteristics of the specific structure) to prevent substantial amounts of heat radiation from passing from pipelines 10 and/or 11 around edges 13 and 14 and into permafrost 1.

If desired, pipelines 10 and 11 are surrounded by a particulate bed of material 17 which is finer in particle size than the material of roadbed 4 and provides a better bed for the pipelines. If the pipelines are insulated around their outer surface, as is often the case, it can be desirable to employ bed 17 because the finer particulate matter making up bed 17 will be less likely to pierce or otherwise damage the insulation on the pipelines than the coarser material in roadbed 4. Thus, pipeline bed 17 can be employed for better load distribution and/or protection of the pipeline or pipelines contained therein.

To better maintain bed 17 around pipelines 10 and 11, bed 17 can be surrounded by a longitudinally extending containment means 18 which is perforated for drainage of water or other liquids therethrough. The shielding protection provided by pipeline bed 17 can also help eliminate the need for corrosion protection. Whether or not pipeline bed 17 is employed, corrosion protection for the pipeline can be used.

Insulation 12 can be any well known thermal insulation such as polystyrene foam, or other material suitable for the purpose intended, and serves the desirable function of thermally insulating the pipelines from the permafrost by reflecting heat up towards the upper surfaces of the roadbed. Additionally, such insulation substantially retards the formation of ground water thermosyphons which increase heat transfer from the pipelines by convection.

FIG. 2 shows permafrost 1 with upper surface 2 wherein a previously existing or prior roadbed 20 was already in place and over which was constructed new roadbed 21. Roadbed 21 contains in its side area, (which is outside prior roadbed 20) pipelines 22 and 23. Pipelines 22 and 23 are surrounded by fine particulate pipeline bed 24 contained in perforated containment means 25. Pipeline bed 24 rests upon insulation means 26 which is curved upwardly on inner side 27 to conform to the outside slope of pre-existing roadbed 20.

EXAMPLE

A roadbed is constructed essentially as shown in FIG. 2 wherein each pipeline is surrounded on its outer surface by polyurethane insulation which in turn is encased on its outer surface by a polyethylene jacket. The pipelines are completely surrounded by sand and enclosed in a perforated containment means and supported on a foamed polystyrene insulation means 26. The remainder of roadbed 21 is formed from gravel.

Reasonable variations and modifications are possible within the scope of this disclosure without departing from the spirit and scope of this invention.

The embodiments of this invention in which an exclusive property or privilege is claimed are defined as follows:

1. A combination roadway and pipeline way for use over permafrost comprising a longitudinally extending roadbed whose bottom area rests on said permafrost, at least one longitudinally extending pipeline embedded in a side area of said roadbed and extending essentially parallel to said roadbed, longitudinally extending insulation means having longitudinal edges, said insulation means being carried in said roadbed between said pipeline and said permafrost, said insulation means extending laterally from both sides of said pipeline a distance sufficient to prevent substantial amounts of heat radiation from passing from said pipeline around said edges of said insulation means and into said permafrost.

2. A combination roadway and pipeline according to claim 1 wherein said pipeline is carried surrounded in a bed of fine particulate matter.

3. A combination roadway and pipeline according to claim 2 wherein said particulate matter is essentially sand.

4. A combination roadway and pipeline according to claim 2 wherein said particulate matter is surrounded by a longitudinally extending containment means which is perforated for drainage.

5. A combination roadway and pipeline according to claim 1 wherein said roadbed is built over a prior roadbed and said pipeline is laid essentially parallel to the outer edge of said prior roadbed and outside said prior roadbed, said prior roadbed and pipeline being both covered by said roadbed.

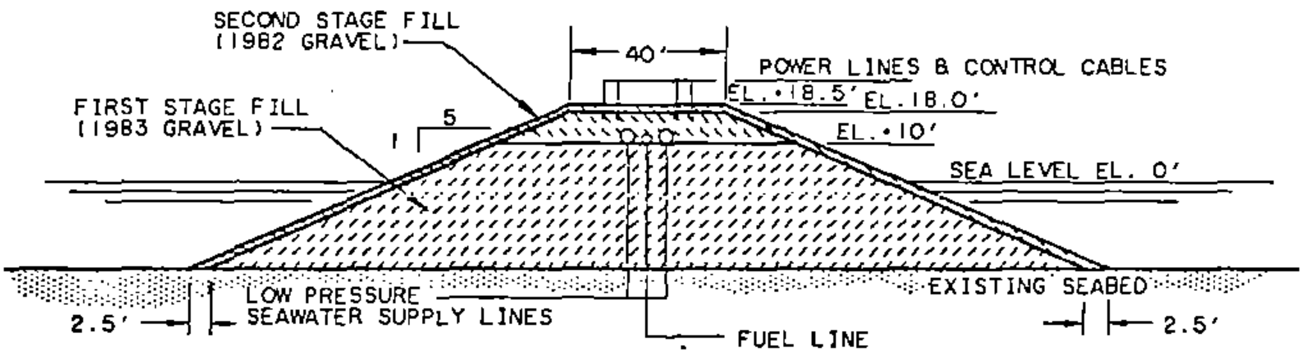
6. A combination roadway and pipeline according to claim 5 wherein said pipeline is carried surrounded in a bed of fine particulate matter.

7. A combination roadway and pipeline according to claim 6 wherein said particulate matter is essentially sand.

8. A combination roadway and pipeline according to claim 5 wherein said particulate matter is surrounded by a longitudinally extending containment means which is perforated for drainage.

9. A combination roadway and pipeline according to claim 1 wherein said pipeline is insulated on its outer surface.

* * * * *



PROPOSED CAUSEWAY EXTENSION

NTS

	PREVIOUSLY APPROVED	NEW APPROVAL REQUESTED
1981 GRAVEL		
1982 GRAVEL		

NOTES:

1) CROWN ELEVATION RAISED 0.5' FROM THAT PREVIOUSLY PERMITTED INCREASING GRAVEL VOLUME BY 3050 C.Y. AND SURFACE AREA IMPACT ON SEABED BY 0.45 ACRES.

2) 1981 CONSTRUCTION FINISHED CROWN ELEVATION TO +10' ELEVATION.

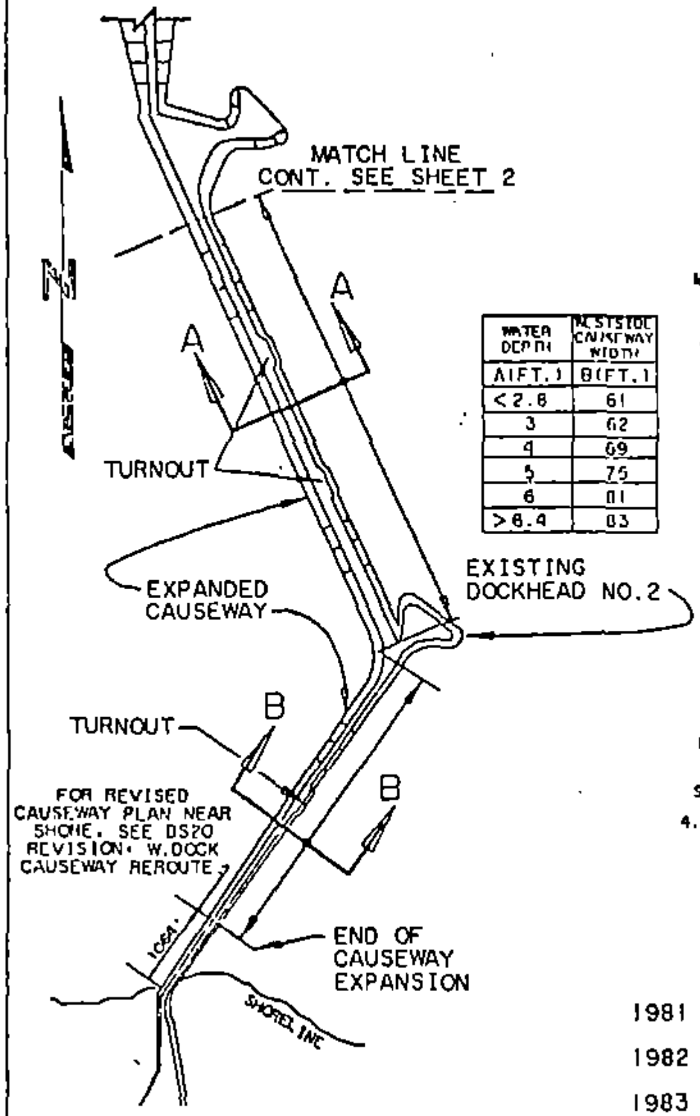
3) FURTHER DESIGN DEFINITION NOW CALLS FOR 2 POWER LINES AND 2 CONTROL CABLES.

LOCATION: T12N-R14E, U.M.
PURPOSE: OIL FIELD DEVELOPMENT
ADJACENT LAND OWNER: STATE OF ALASKA

PROPOSED CAUSEWAY EXTENSION
WATERFLOOD PROJECT
PRUDHOE BAY
NORTH SLOPE BOROUGH
STATE OF ALASKA

APPLICATION BY: ARCO ALASKA INC.
SHEET 7 OF 14
DATE: APRIL '82

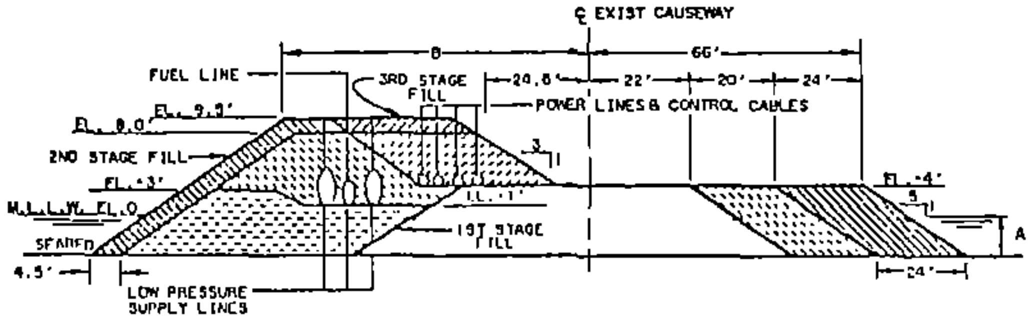
2004320202



WATER DEPTH	WESTSIDE CAUSEWAY WIDTH
A(FT.)	B(FT.)
<2.8	61
3	62
4	69
5	75
6	81
>6.4	83

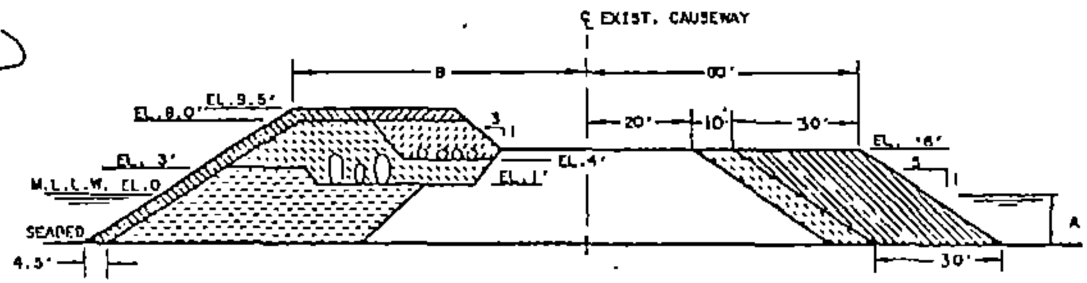
PLAN

NTS



SECTION A-A

NTS



SECTION B-B

NTS

	PREVIOUSLY APPROVED	NEW APPROVAL REQUESTED
1981 GRAVEL	[pattern]	
1982 GRAVEL	[pattern]	[pattern]
1983 GRAVEL	[pattern]	[pattern]

ADDITIONAL GRAVEL VOL.: 58,007 C.Y.
ADDITIONAL SURFACE IMPACT: 5.08 ACRES

LOCATION: T12N-R14E, U.M.
PURPOSE: OIL FIELD DEVELOPMENT
ADJACENT LAND OWNER: STATE OF ALASKA

PROPOSED CAUSEWAY
EXPANSION REVISED
WATERFLOOD PROJECT

PRUDHOE BAY
NORTH SLOPE BOROUGH
STATE OF ALASKA

APPLICATION BY: ARCO ALASKA INC.
SHEET 3 OF 4 (REV) DATE: APRIL '82

2004320201

Appendix B

CALCULATION PROCEDURE
FOR INSULATION THICKNESS

SECTION 8 - SPECIAL DESIGN BURIAL FOR CASED ROAD AND WILDLIFE CROSSINGS

The Milne Point Project will require at least four road crossings and two crossings for migrating wildlife. Criteria call for these crossings to be buried and capable of long-term performance with little or no thaw settlement. The insulation system planned for the project is not suitable for direct burial in permafrost or gravel fill without long term degradation of the insulation. A cased buried section is therefore required in order to maintain an air space around the insulation jacket. The casing also serves to protect the insulated pipeline from heavy wheel loads at road crossings.

The preliminary design for these buried crossings is shown in Exhibit 51. A cover depth over the casing of 3 feet (127 cm) is proposed with a bedding layer of 1.5 feet (46 cm). The bedding serves two purposes. First, elevation of the casing is necessary to prevent water from standing or flowing in the annulus between the insulated pipe and casing. Second, the 1.5 foot of bedding allows thaw beneath the casing without accompanying thaw settlement (if 32^{o}F or 0^{o}C isotherm remains within gravel).

An evaluation was made of the proposed design using a steady-state quasi-static thermal solution developed by Hwang et al, 1980. This method is suitable for preliminary design and evaluation of insulated pipelines. It is probably suitable for final design where the pipeline insulation factor for worse case conditions clearly exceeds the calculated required insulation factor. Since the quasi-static solution assumes a constant initial temperature without accounting for the variation of ground surface temperature, the results for most cases can only be considered preliminary. In order to develop a final effective design, other analytical methods, such as two dimensional simulation, may be required to properly evaluate the effect of seasonal ground temperature variation.

Results of Evaluation

The Milne Point Project special design crossings were evaluated assuming the use of gravel bedding so that the 32°F (0°F) isotherm will remain within stable material thereby preventing thaw settlement. Using Exhibit 51 as required input data, the evaluation was made in five parts.

1. Calculate insulation factor (I_F) for cased crossing assuming no insulation value for air in annulus of casing. Because the outside of the insulation jacket is not equal to the radius of the casing (R_o) an equivalent thermal conductivity must be calculated for insulation plus annulus.

   Therefore:

   Equal. $$K_{INS} = \frac{0.026W/(m\cdot K)(16.5cm)}{7.6cm}$$

   $$= 0.0565\ W/(m\cdot K)$$

$$= S/R_o = \frac{16.5cm}{35.6cm}$$

$$= 0.46$$

$$= \frac{Equal.K_{INS}}{K_1} = \frac{0.0565W/(m\cdot K)}{2.95W/(m\cdot K)}$$

$$= 0.019$$

From Exhibit 52 the insulation factor for the cased crossing = 33

$$I_F = 33$$

2. Calculate insulation factor for cased crossing assuming dry still air in annulus of casing. The thermal conductivity of dry still air is 0.016 W/(m K), but for evaluation assume the air has a higher thermal conductivity equivalent to polyurathane (0.026 W/(m K).

$$\acute{c} = 0.46$$

$$6 = \frac{K_{INS}}{K_1} = \frac{0.026W/(m\cdot K)}{2.95W/(m\cdot K)}$$

$$= 0.0009$$

From Exhibit 52 the insulation factor for the cased crossing = 70

$$I_F = 70$$

3. Calculate insulation factor required for cased crossing using steady-state thermal solution to prevent thawing of permafrost soils:

$$\text{Thermal ratio} = a = \frac{K_2(T_G-T_F)}{K_1(T_P-T_F)}$$

$$= \frac{0.97W/(m\cdot K)(-8.6°C)}{2.95W/(m\cdot K)(82°C)}$$

$$= -0.034$$

$$\mu = h_o/R_o = \frac{127cm}{35.6cm} = 3.6$$

$$D_s/R_o = \frac{46cm}{35.6cm} = 1.3$$

Required insulation factor for steady-state condition from Exhibit 53 = 50

$$I_F = 50$$

4. Calculate insulation thickness required for cased crossing to prevent thawing of permafrost assuming no insulation value for air in casing annulus:

$$I_F = \frac{1}{\theta} \ln \left(\frac{1}{1-}\right)$$

$$\theta = \frac{\ln \left(\frac{1}{1-}\right)}{I_F}$$

$$= \frac{\ln \left(\frac{1}{1-.46}\right)}{50}$$

$$= 0.0123$$

$$K_{INS} = K_1 \cdot \theta$$

$$= 2.95W/(m \cdot K) \cdot 0.0123$$

$$= 0.0363W/(m \cdot K)$$

$$\text{Thickness Polyurathane} = \frac{0.026W/(m \cdot K)}{0.036W/(m \cdot K)} \cdot 16.5cm$$

$$\text{Required Thickness} = 11.8cm = 4.7 \text{ inches}$$

5. Calculate thickness of bedding required to maintain 32°F (0°C) isotherm within gravel assuming no

insulation value for air in casing annulus:

From Exhibit 53 determine Ds/R_o required for an $I_F = 33$, $a = 0.034$, and $= 3.57$

Required $Ds/R_o = 3.5$

$Ds = 35.6 \quad 3.5$

Required bedding = 125 cm = 4.1 feet

The air present in the casing annulus will have some impact on the calculated depth of thaw, but the actual thaw depth will be difficult to establish with this type of analysis since air circulation will be present in the annulus during summer (when air temperatures are above freezing) and no air circulation is expected during the winter (when air temperatures are coldest) due to snow blocking end of casing.

The option of adding approximately 2 inches of insulation to the pipe would require a special order of insulated pipe. An alternative would be the addition of polystyrene board insulation below the casing. The width required for a planer insulation break would be a minimum of three casing diameters (7.0 feet) to either side of the casing. Insulation thickness for the board stock would be greater than 2 inches due to the increased distance from the insulated pipe and due to the higher thermal conductivity of polystyrene insulation.

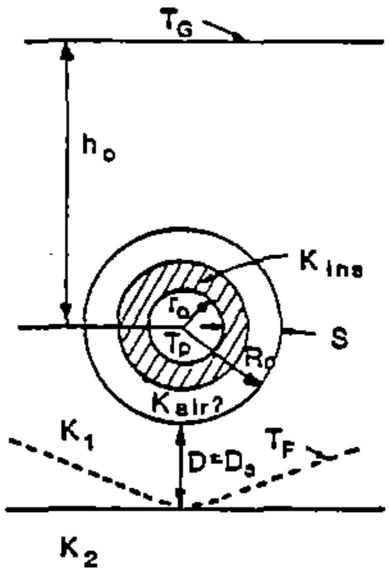
The option of increasing the gravel bedding thickness beneath the casing appears unrealistic. Addition of an additional 2.6 feet of gravel bedding thickness would increase the already nearly 7 foot embankment to nearly 9.5 feet. Insulation may be a better choice.

For final design a more detailed two-dimensional analysis is needed to determine if insulation below the casing is required and if so what insulation thickness is optimum for long-term performance. The preliminary steady-state thermal analysis does not clearly indicate whether or not additional insulation is necessary.

Exhibit 51

MILNE POINT PROJECT SPECIAL DESIGN BURIAL

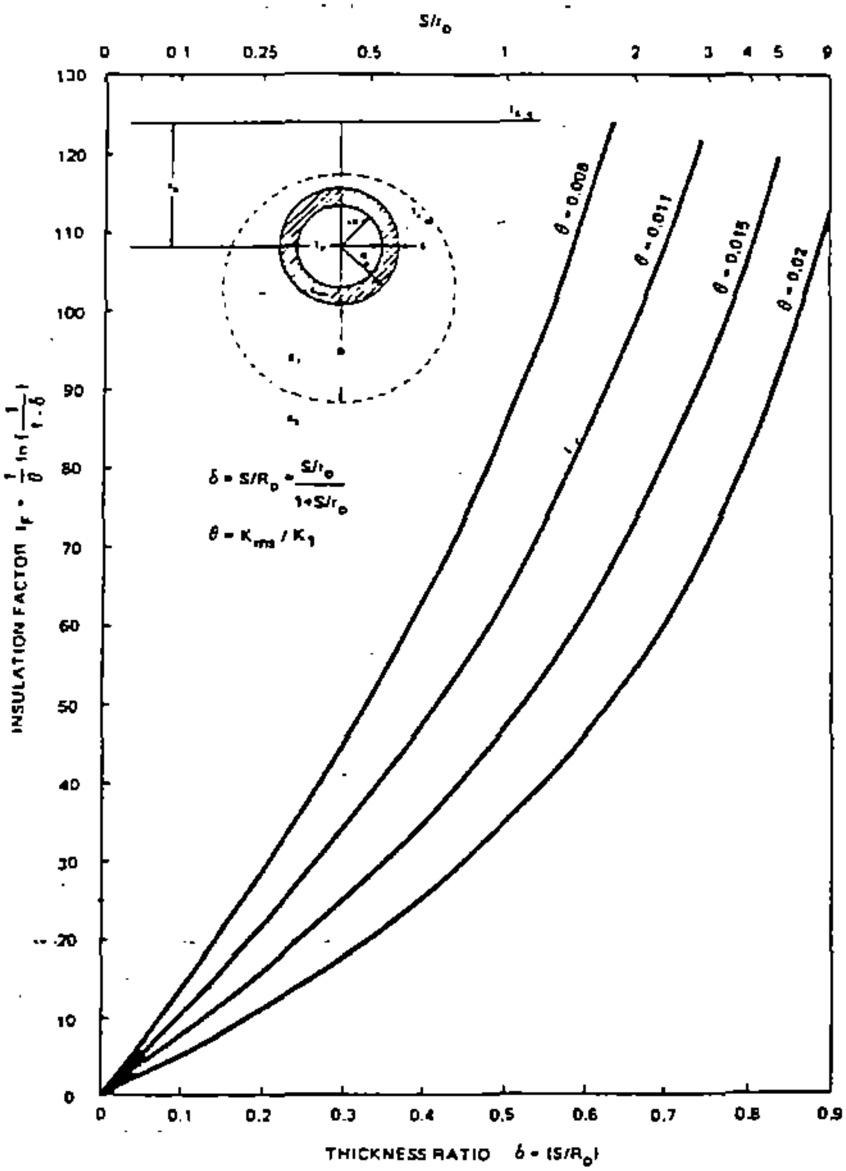
CASED ROAD AND WILDLIFE CROSSINGS



$T_F = 0\ ^\circ C$
OIL TEMPERATURE = T_p = 82 °C
MEAN ANNUAL GROUND TEMPERATURE = T_G = −8.6 °C
PIPELINE RADIUS = r_o = 17.8 cm
CASING RADIUS = R_o = 35.6 cm
CASING WALL THICKNESS = 1.3 cm
DEPTH TO CASING CENTERLINE = h_o = 127 cm
INSULATED PIPE RADIUS = 25.4 cm
INSULATION THICKNESS = S = 7.6 cm
GRAVEL THICKNESS BELOW CASING = D = 46 cm
CASING ANNULUS = 8.9 cm
POLYURETHANE THERMAL CONDUCTIVITY = K_{ins} = 0.026(w/m·k)
GRAVEL THERMAL CONDUCTIVITY = K_1 = 2.95 w/(m·k)
PERMAFROST THERMAL CONDUCTIVITY = K_2 = 0.97 w/(m·k)

Exhibit 52

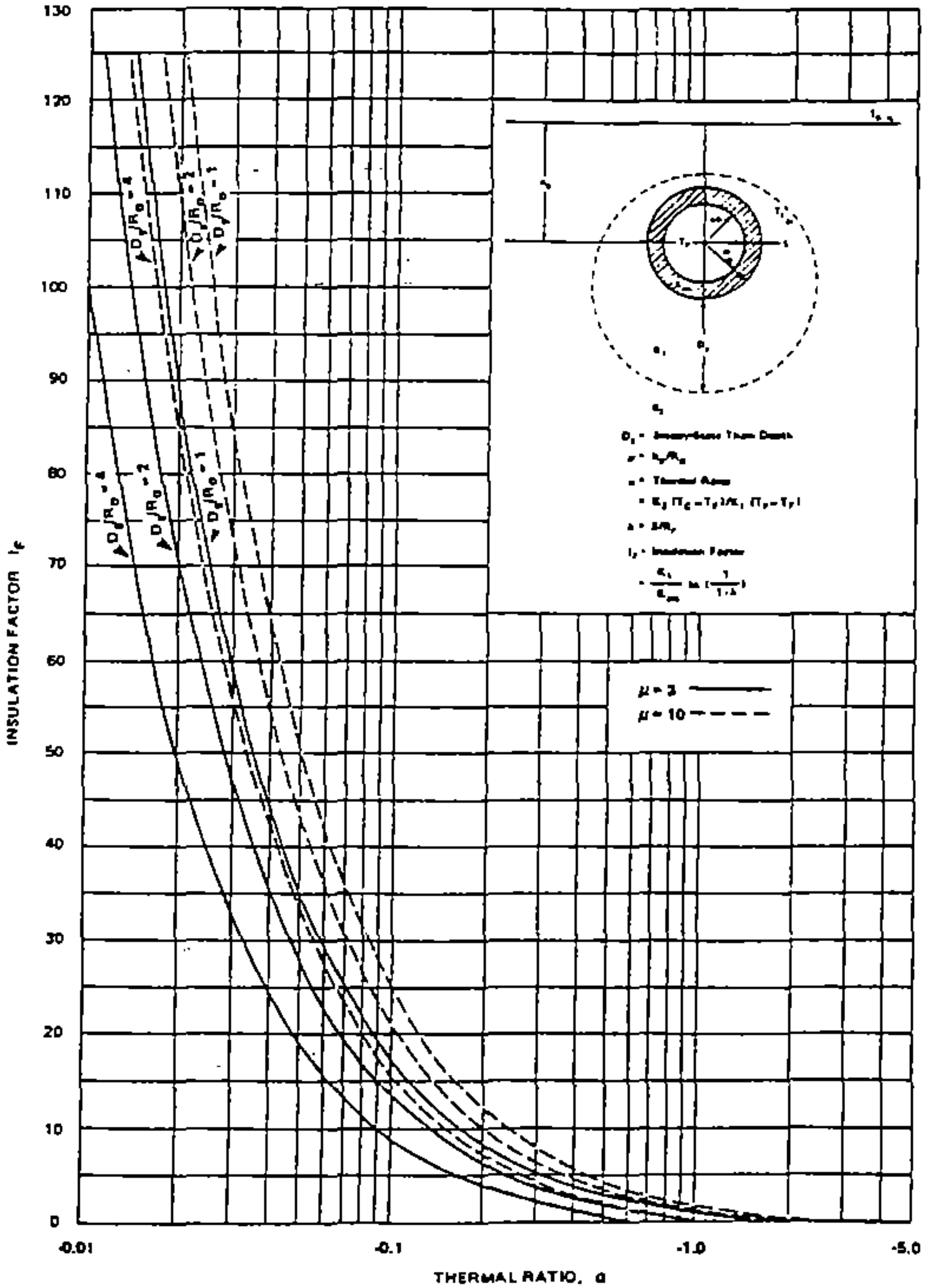
Insulation Factor vs. Thickness Ratio



From Hwang et al, 1980

Exhibit 53

Thermal Ratio vs. Insulation Factor for Steady-State Thaw Depth



From Hwang et al, 1980