GEOTECHNIC EVALUATION of the Proposed ALCAN GAS PIPELINE in Alaska

FPC Docket CP76 - 433 et al.

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October 1976 Report 1455 - 1

Prepared for the

Bureau of Natural Gas
FEDERAL POWER COMMISSION
Washington, D.C.

under

Contract FP-1791

4 October 1976

The contents of this report reflect only the views of the contractor, IROQUOIS RESEARCH INSTITUTE, which is solely responsible for the facts, accuracy, analysis, evaluations, conclusions and recommendations presented herein. This report does not purport to represent the official views nor policies of the Federal Power Commission.

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Iroquois Research Institute
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GEOTECHNIC EVALUATION

OF THE

ALCAN PIPELINE SYSTEM IN ALASKA

Iroquois Research Institute

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ACKNOWLEDGMENT

I am deeply appreciative of the dedicated and exhaustive efforts by IROQUOIS RESEARCH INSTITUTE personnel and associates who produced this volume and its companion reports in less than two months. Their remarkable efforts are given due recognition herein as Contributors in testimony to the results of their exceptional professional endeavor.

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4 October 1976

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4 October 1976

Federal Power Commission
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Attention: Bureau of Natural Gas
Michael J. Sotak

Gentlemen:

We are pleased to submit herewith our final Geotechnic Analysis of the proposed Alcan pipeline system in Alaska as requested under your contract FP-1791.

This volume contains our geotechnic analysis of the Applicant's Submission and our derivative conclusions pertinent to the integrity of the proposed Pipeline. Conclusions have been limited to those critical factors which may represent a potential threat to either the environment or the public safety. This volume has been assigned catalog card number 76-46837 by the Library of Congress.

Our earlier analysis under the same contract has already been published in the September, 1976, Alcan Pipeline supplement to the Federal Power Commission's Final Environmental Impact Statement entitled "Alaska Natural Gas Transportation Systems."

With kindest regards, I remain

Respectfully,
Iroquois Research Institute

B W Poirier

Bernard W. Poirier
Director

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F O R E W O R D

This report is the final Geotechnic Evaluation of the Application by the Alcan Pipeline Company to transport natural gas from Prudhoe Bay south and east to the Canadian border. The Alcan application is for a route from Prudhoe Bay south, parallel to the Alyeska Oil Pipeline to Delta Junction and then southeast along the Alaska Highway to the Alaska-Yukon border.

This Geotechnic Evaluation analyzes the critical factors affecting Alcan pipeline integrity which might pose a potential threat to the environment and/or the public safety. Derivative conclusions are then presented which could improve the potential integrity of the Alcan Pipeline System. This evaluation was conducted by the IROQUOIS RESEARCH INSTITUTE for the Bureau of Natural Gas, Federal Power Commission (FPC).

Major inputs to this Final Geotechnic Evaluation included the Alcan Pipeline Company _Application for Certificate of Public Convenience_; the Federal Power Commission (FPC) _Alaska Natural Gas Transportation Systems Draft_ and _Final Environmental Impact Statements_; the Department of the Interior (DoI) _Alaska Natural Gas Transportation System Final Environmental Impact Statement_; the DoI _Final Geotechnic Evaluation of the Alaska Pipeline_ and extensive additional technical data obtained from various other sources.

For easy reference, the material contained herein is presented in the order defined by the FPC _Environmental Impact Statement_ Table of Contents, modified to fit the Alcan application. Only those subjects jointly identified by the FPC and IROQUOIS as being pertinent to the pipeline system's integrity are included.

Each of the subjects addressed has been further subdivided into the following elements for consistency and clarity:

- Applicant's Submission
- Analysis of Submission
- Conclusions

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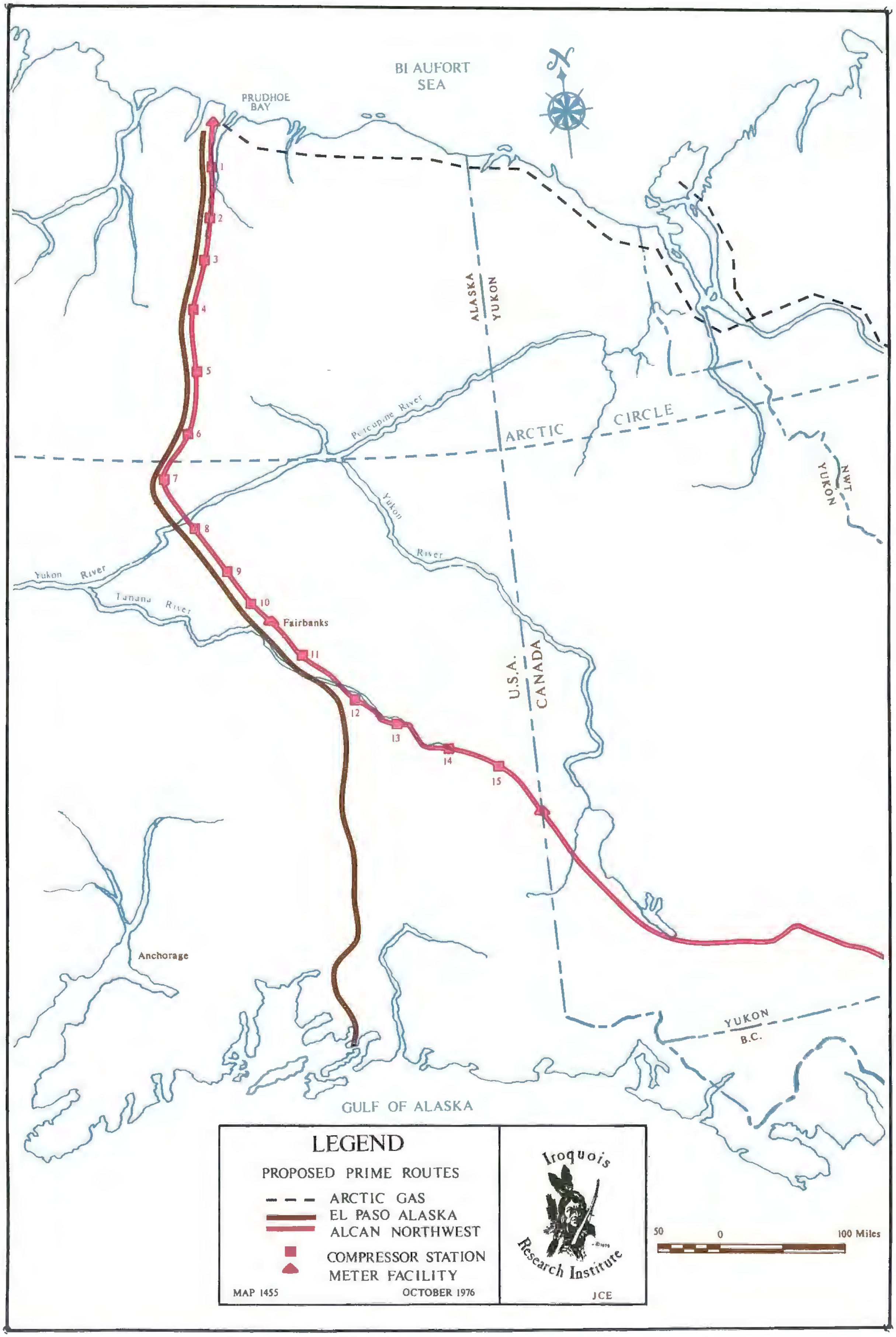
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INTRODUCTION

The North Slope of Alaska was one of the loneliest places on earth until 1968, when oil in great quantity was discovered near Prudhoe Bay. The discovery changed the land, about which relatively little was known, into a scene of mechanized technology into which great aerial and seagoing armadas have been pouring men and equipment.

As early as February, 1969, the construction of the first great arctic pipeline was announced to transport crude oil southward across the tundra, the forests and the mountains to the Alaskan port of Valdez. Various legal suits by Natives, environmental groups, and fishermen delayed the issuance of construction permits by the Department of the Interior. Eventually, Congress passed the Trans-Alaska Pipeline Authorization Act, signed into Law by President Nixon in November, 1973.

Natural gas produced during crude oil production will be reinjected into the North Slope reservoir until the means to distribute the Alaskan natural gas to consumer markets are established.

The first application to provide an independent natural gas pipeline from the North Slope was filed before the Federal Power Commission on March 21, 1974, by the Alaskan Arctic Gas Pipeline Company (Docket CP75-96). The prime route would traverse eastward along the coast of the Beaufort Sea and near the Canadian oil and natural gas fields at the mouth of the Mackenzie River, thence southward toward the center of North America. Companion applications were also filed to carry arctic natural gas to the east and west coasts of the contiguous United States.

El Paso Alaska Company filed a competitive application with the Federal Power Commission on September 24, 1974, for the construction and operation of a natural gas pipeline from Prudhoe Bay to Gravina Point in Prince William Sound, Alaska. The El Paso plan is to establish a tanker fleet to transport liquid natural gas from Gravina Point to the west coast of the contiguous United States and thence to distribute natural gas eastward through the existing continental pipeline network.

On January 23, 1975, the Federal Power Commission consolidated all then related applications to one common Docket, number CP75-96, et al.

The Department of Interior and the Federal Power Commission subsequently issued environmental impact statements related to the prime and alternative routes as well as proposed and alternative marketing methods.

Recently, the Alcan Pipeline Company filed a competitive application on July 9, 1976, under Federal Power Commission Docket number

CP76-433, et al. On August 5, 1976, the Federal Power Commission requested the Iroquois Research Institute to evaluate the environmental consequences of the geotechnic characteristics of the proposed Alcan pipeline project in Alaska, the object of this report.

This volume and companion documents represent a continuing participation by Iroquois Research Institute in the environmental analysis of every major pipeline proposed in Alaska since the Prudhoe Bay discoveries.

As in the past, Iroquois has made every conscientious effort to provide an expert, unbiased analysis and evaluation. No security or financial interest in any energy company or in any utility is owned by any Iroquois employees or associates, nor by any member of their households, assigned to this project.

During this Alcan evaluation, Iroquois experts aerially inspected by low-level flight the proposed Alcan pipeline alignment in relation to existing utility corridors and the on-going Alyeska oil pipeline construction. During the last five years, Iroquois has analyzed environmental aspects of over 6,800 miles of potential and actual pipeline corridors in Alaska. In addition, over 200,000 pages of technical and scientific documentation associated with Alaska pipelines and arctic environmental engineering have been examined and studied.

Except for unique local conditions, the evaluation of the proposed Alcan natural gas pipeline alignment shows that no geotechnical objections can be raised over most of the routing proposed.

However, a serious reviewer will note that a combination of situations, in 1976, does cloud the safety and integrity of a natural gas pipeline in some areas of Alaska if authorized under the existing shortcomings of the arctic metallurgical state-of-the-art, the absence of appropriate cold weather technical standards, the lack of supportive arctic test pipeline and evaluation data, the inadequate design criteria for Alaskan operational safety and controls, and a diminishing decision-making timetable. These observations apply, in varying degrees, to the pipeline designs proposed by all the competing applicants.

To recommend major Federally-funded research programs to solve apparent deficiencies would be outside the scope of our evaluation.

C. ENVIRONMENTAL IMPACTS OF THE PROPOSED ACTION

2. Topography

a. General

i. Applicant's Submission

The Applicant did not provide a discussion of the topographic impacts of the proposed pipeline and mentioned revegetation as a mitigating measure in one sentence of the discussion of land use impacts.1/

ii. Analysis of Submission

As indicated above, the Applicant's Submission is deficient in the area of topographic impact.

The topographic impact of the proposed Alcan pipeline from Prudhoe Bay to Delta Junction is generally the same as that of the proposed El Paso pipeline, which was described in the Federal Power Commission's Final Environmental Impact Statement of April 1976. Since that document was written, direct observation (8/25/76) shows that regrading and revegetation have been accomplished along the Alyeska route not only on significant portions of the pipeline right-of-way, but also in several borrow pits, spoil disposal areas, and some access roads. In areas of pipeline burial where the new grasses have had an opportunity to mature, the revegetated work pad resembles a raised sward four or more feet above the surrounding terrain. (This, of course, is not the case in hill-side cuts.) It is unnatural to the extent that the work pad runs in straight lines and that the new vegetation does not blend in with the surrounding climax species. In forested regions, these effects are more pronounced.

The improved borrow pits and spoil disposal areas have not yet blended into the surrounding landscape, primarily due to the lack of climax vegetation. However, it is possible to predict that, with the passage of time, most of these areas will be visually integrated into the natural topography.

The bedrock quarries are indeed scars, especially hill-side vertical quarries. Bedrock quarries can be, and to some extent have been, rehabilitated at ground level by using them as revegetated spoil disposal areas.

The grasses currently used for revegetation are native Alaskan species which were identified and cultivated by Dr. William Mitchell of the Palmer Agricultural Experiment Station. Since Dr. Mitchell's work with these species is recent, there is a lack of seed.

1/Applicant's Submission, Exhibit Z-1, Vol. 1, Sect. 3, p. 3-4.

This lack has slowed the Alyeska revegetation effort and must be considered in any proposed revegetation for a natural gas pipeline.

This is not to say that the topography will be unimpacted by the proposed gas line, but there is evidence that, with care, the impacts can be lessened. However, the topography cannot be restored to a natural condition once a project of this magnitude has passed through it. (See Figures 2 and 3)

Figure 2 - Alyeska Borrow Pit Near Salcha River

A partially restored borrow pit used by Alyeska is located at Alcan milepost 489.6. The pit has been regraded except in the center disturbed area and for the borrow material pile awaiting removal. Revegetation is already in process at the near (eastern) edge of the pit and in the cleared right parcel. (Iroquois photo 8/26/76)

Figure 3 - Old Borrow Pit Area

Contrasting with the photograph at the left is this older borrow pit near Eielson Air Force Base, which graphically demonstrates what may happen if care is not taken. The location is near Alcan milepost 473. (Iroquois photo 8/26/76)

There are highly erosive silts in the hills around Fairbanks which will require special care in erosion control and re-vegetation. Likewise, there are fine sands south of the Tanana River crossing near Mile Post 655 which are erosion prone.

From Tok Junction to the Yukon border, approximately 15% of the proposed right-of-way passes through swampy areas of saturated lacustrine deposits and thaw lakes. These areas will require thick gravel work pads for summer construction to proceed as proposed by the Applicant. This would considerably impact the existing topography and drainage system by imposing a berm at least 40 feet in width straight across these swamps. This can be avoided in half the swamp areas by rerouting the pipeline to the uphill side of the Alaska Highway where relatively well-drained soils are encountered. A lesser impact would be made on the remaining swamps if a winter construction schedule were followed for those areas.

The topography can also be altered by pipeline induced mass wasting and landslides which are discussed in Section C.3.d.

iii. Conclusions

(1) The Applicant's discussion of topographic impacts is insufficient.

(2) Alyeska experience has demonstrated the ability of revegetation to lessen topographic impacts.

(3) Revegetation may be hindered by a lack of native Alaskan grass seed.

b. Slopes

i. Applicant's Submission

The Applicant described the topography in general, non-quantitative terms such as "low," "steep," "rolling," "broad," etc. Elevations and local relief are stated numerically for each physiographic province, but the only quantitative citation for slope is "Coalescing outwash fans from the Alaska Range slope 20-50 feet per mile northward. . ."1/

Elsewhere, the Applicant presented strip maps which contain generalized terrain descriptions for each of twenty-five separate segments of the proposed line.2/ Again, slopes are not described in quantitative terms.

ii. Analysis of Submission

The primary reason for describing the topography is to identify problem areas related to steepness of slopes and the direction of the pipeline relative to those slopes. The Applicant has addressed this aspect in neither the environmental baseline nor impact sections. Slope stability is given only a half-page discussion in the most general terms.

iii. Conclusion

The Applicant has not described the steepness of slopes to be encountered, and thus has not specified the angles at which slopes are to be crossed nor in any way discussed specific areas where slope stability might be a problem.

1/Applicant's Submission, Exhibit Z-1, Vol. 1, Sect. 2, p. 2-42.
2/Ibid., Exhibit Z2, Sect. 1.

c. General Drainage

i. Applicant's Submission

A brief description of the major streams is given for each of the physiographic regions.1/ This includes channel patterns, orientation of streams, valley shapes, and (rarely) width of floodplains. Principal streams crossed by the proposed route are listed, but no dimensions are given.2/

Also given are brief descriptions of a variety of geomorphic features and deposits related to rivers and flood streams, thermokarst topography, thaw lakes, drained basins, initial sand dunes, stone nets, stone stripes, stone garlands, a variety of glacial materials, and aufeis.3/

One-third of a page4/ is devoted to river crossings, where it is noted that there will be seven principal crossings and about 87 all together. Aufeis, as a phenomenon, is described under Hydrology.5/ No details regarding the distribution of character of aufeis are given but reference is made to observations along the existing corridor by the U.S. Geological Survey and aufeis studies by the Institute of Water Resources, University of Alaska. The importance of vertical and lateral scour are noted, but no data are given.6/

ii. Analysis of Submission

The generalized descriptions of streams and the specific related features are adequate to show an awareness of their existence and some of the problems related to streams.

Aufeis is given less discussion than its importance warrants. Details of distribution and character would be preferable to merely citing three published studies.

The major reason for describing drainage characteristics is to delineate potential problems at river crossings and to provide a basis for designing materials and construction methods to overcome them. Specifically, such problems include lateral erosion, bed scour, and aufeis. Numerical data for these aspects are needed for all major and probably most minor stream crossings.

1/Applicant's Submission, Exhibit Z-1, Vol. 1, Sect. 2, pp. 2-20 to 2-52.
2/*Ibid*., p. 2-267.
3/*Ibid*., p. 2-20 to 2-52.
4/*Ibid*., Sect. 1, p. 1-32.
5/*Ibid*., Sect. 2, p. 2-293.
6/*Ibid*., p. 2-290.

iii. Conclusions

(1) The Applicant's overview of topography and geomorphic features is, in general, adequate to show an awareness of these aspects as they might affect pipeline construction.

(2) The Applicant did not supply specific numerical data on stream crossings, which must be available before designing and planning pipeline stream crossings.

(3) Similarly, the occurrence and character of aufeis on specific streams is not adequate, considering the importance of this phenomenon and availability of data.

C. ENVIRONMENTAL IMPACTS OF THE PROPOSED ACTION

3. Geologically Related Impacts

a. Resources

i. Applicant's Submission

The Applicant estimated the resources required for construction of the pipeline[1] without discussing the impact of such usage. The Applicant's brief section entitled "Impact of Use of Resources During Operation and Maintenance"[2] implies, and indeed seems to refer to, a similar but non-existent section for the construction phase of the proposed project.

ii. Analysis of Submission

The impact of the proposed Alcan gas pipeline on geological resources is essentially the same as that of the proposed El Paso project, which the Federal Power Commission evaluated in its Final Environmental Impact Statement of April 1976. Exceptions are noted below.

Since the proposed Alcan project does not include LNG facilities, it would not provide a potential collection and export facility for offshore gas fields either in the Gulf of Alaska or in the area east of Prince William Sound. Although the Applicant did not address this point, a spur line could probably be built to connect the Alcan pipeline to coastal regions if the quantity of offshore gas justified the efforts. The Applicant's proposed pipeline would not have capacity for any excess gas over and above the proven Prudhoe Bay reserves.

The Alcan project would have even less effect than the El Paso gas pipeline in opening up new areas to mineral exploitation since Alcan's proposed route follows existing access routes.

Alcan estimated that it will require 11.3 million cubic yards of borrow materials to complete the proposed project. If this estimate is based upon the cross-sections illustrated in Drawings No. APC S9-10 and APC S9-11,[3] the estimate is probably low. These cross-sections only show the Alyeska and Alcan pipelines on flat ground with no side slopes. In several possible configurations of the pipelines on side hill slopes, it would be necessary for Alcan to build completely new work pads or to drastically widen existing work pads. (This is further discussed in Section D.1.b.1.(1).) In addition, since the buried gas pipeline is designed to withstand thermal stress without appreciable strain, it need not use Alyeska's

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1/Applicant's Submission, Exhibit Z2, Sect. 6, pp. 28-39.
2/Ibid., Exhibit Z-1, Vol. 1, Sect. 3.2.6, p. 3-20.
3/Ibid., Exhibit Z2, Sect. 1, pp. 26-27.

trapezoid configuration to allow for thermal strain; therefore, it might be economical not to precisely parallel the above-ground portions of Alyeska pipeline, but rather to save between five and ten side bends per mile by paralleling the general Alyeska alignment instead of the precise pipeline. The use of this procedure would require the construction of one mile of new work pad for every two miles that this procedure is followed.

From Prudhoe Bay to Delta Junction, the proposed Alcan project would have the same impact on aggregate resources already strained by the Alyeska construction as the El Paso project would have. However, from Delta Junction to the Yukon border, the impact on aggregate resources should not be as great. Due to the high proportion of granular thaw stable and/or non-permafrost soils, less work pad construction would be required. Approximately 10-15% of this segment would require normal work pads; it should be sufficient for the remainder to merely grade the in situ soils. The boring logs included in the Submission indicate a greater availability of gravel which has not been impacted by the Alyeska route.

iii. Conclusions

(1) Geological resource impacts of the proposed Alcan pipeline are essentially the same as those reported by the Federal Power Commission in its Final Environmental Impact Statement of April 1976.

(2) The Alcan project would provide less stimulus for additional resource exploitation.

(3) The Applicant has probably underestimated its gravel requirement.

b. Permafrost

i. Applicant's Submission

The Applicant defined permafrost and explained its origin and characteristics in detail.[1] Factors that influence the formation or, more importantly, the distribution of permafrost are well described (vegetation, snow cover, water bodies, fire, etc.).

Occurrence of permafrost in each of the physiographic regions is described with some quantitative information about depth of the permafrost table, thickness of permafrost, moisture content, and permafrost-related features (ice wedges, stone polygon nets, etc.) in specific areas.

The influence of permafrost such as rooting of plants and solifluction is briefly indicated. Also, engineering modification of

1/Applicant's Submission, Exhibit Z-1, Vol. 1, Sect. 2.1.4, pp. 2-59 to 2-67.

the environment which cause thermal imbalance and their effects on the engineering structures (roadways, pile foundations) are mentioned.

ii. Analysis of Submission

The Applicant has described the origin, characteristics and boundaries of permafrost. Some of the factors which influence the formation and distribution of permafrost are provided. However, no physical and mechanical properties (except range of moisture contents in fine-grained soils) which are vital to the design of buried pipeline are mentioned or assessed.

The physical and mechanical properties of permafrost which are of primary concern for the buried pipeline design are

(1) Frozen dry density

(2) Water content

(3) Coefficient of thaw consolidation

(4) Shear strength

(5) Creep strength

(6) Permeability

The nature of ice bonding and its inter-phase relationship to other soil constituents have to be known for the assessment of permafrost characteristics. In addition, some of the thermal properties of frozen soils such as thermal conductivity, specific heat and latent heat, should be known to determine the anticipated depth of active layer under differing conditions of soil strata above which the construction activities will take place.

For engineering purposes, permafrost characteristics are related primarily to temperature, ice content, and distribution and continuity of permafrost layers. Of equal or greater importance are the thickness and character of the active layer, depth of the permafrost table, and occurrence of talik (unfrozen) layers, coefficient of consolidation, permeability, and soil conductivity.

In the section on regional occurrence of permafrost, the Applicant has provided short verbal descriptions and some numerical data as to depths of the permafrost table, permafrost temperature, and moisture contents. Unfortunately, these numbers are not referenced, so it is not clear whether they are based on studies by the Applicant or are from the open literature. In any case, the data seem reasonable but cannot be verified since the sources are not cited.

More importantly, the quantity of information on the character of permafrost at specific localities along the proposed route is totally inadequate for pipeline design or construction planning. Detailed borehole data, such as that developed for the oil pipeline, will be necessary.

The Applicant has provided some borehole data along the proposed route south of Delta Junction.1/ Some of it is from public sources, some specifically obtained for this project by the Applicant. The coverage is spotty, with large gaps separating some areas of fairly continuous coverage.

Borehole data on permafrost characteristics may be sufficient in some areas to permit general design specifications, but continuous, close coverage will be necessary before actual construction.

The proposed pipeline route will traverse a wide range of subsoil conditions ranging from continuous or discontinuous permafrost to unfrozen soils. The construction of the pipeline will have significant impact on the permafrost regions as well as upon the unfrozen areas.

In permafrost regions, the removal of the surficial vegetative cover or trafficking over a thin snow cover will cause thermal imbalance and a deeper active layer will be created. Thus, many problems such as slope instability, differential settlement, loss of bearing capacity, and surface erosion will be encountered. Especially in areas where the ice-rich soils are present in a delicate thermal equilibrium, a slight change can upset the equilibrium and induce significant thaw.

On the other hand, after construction, the chilled gas will create a bulb of frozen soils around the pipe in previously unfrozen ground. Consequently, the pipe could be overstressed due to uplift, or by a serious change in the drainage pattern in the vicinity of the pipeline area which would create ponding as well as side channeling. The geometric size of the frost bulb is variable, depending on such factors as the existence of frost-susceptible soils, the nature of the soil type, the position of the ground water table, and the operational temperature of the gas in the pipe. Nevertheless, the presence of a frost bulb in previously unfrozen ground near stream crossings and subsurface drainage areas would have significant secondary impacts.

Natural disturbances such as climactic change, stream channel migration, lake drainage, fire, and solifluction along the pipeline route prior to the commencement of the gas flow could endanger the integrity of the pipeline by loss of adequate support, floating of the pipeline or slope failure.

Once thermal degradation in permafrost is initiated, it is difficult, if not impossible to reverse, and it continues until a

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1/Applicant's Submission, Exhibit Z9 and Z9 Supplement.

new thermal equilibrium has been reached. Generally, a long time is required to achieve the new equilibrium.

The major impact of the pipeline on permafrost would take place between the initial disturbance during the construction and the initiation of chilled gas flow operations. The thaw-freeze cycle would alter the characteristics of the surrounding soils, possibly resulting in significant damage to the unchilled pipeline as well as to the environment.

The unchilled, newly laid pipeline could cause thermal melting and thermal erosion during the intervening thaw periods. The magnitude of the problem is unknown. However, the ditch could become a water-filled trench or a french-drain collecting all surface and some subsurface seepage water, thus weakening the subgrade bearing capacity. This will reduce the subgrade reaction to the soil-pipe interface resulting in the over-stressing of the pipeline due to differential settlement. On sloping terrain, potential slope instability could be created by a pipe-filled trench capturing local drainage and causing erosion of the materials supporting the pipe.

Thus, the impact of the pipeline on the permafrost as well as on the unfrozen ground affecting thermal degradation, thermal aggradation and erosion, must be mitigated to the greatest extent possible by proper design measures.

iii. Conclusions

(1) The Applicant's baseline data on permafrost is inadequate except for the most preliminary planning.

(2) The Applicant's discussion of permafrost impacts, both the impact of permafrost on the pipeline and the impact of the pipeline on permafrost, is insufficient to adequately analyze.

c. Frost Heave

i. Applicant's Submission

The Applicant has submitted a consultant's report entitled "Alcan Pipeline Project, Frost Heave Considerations,"[1/] where it was noted that frost heave is caused by the volumetric expansion of in situ pore water upon freezing, as well as by the freezing of water that migrates to the freezing front. The report states that the former component is usually small, as compared with the latter, which is also termed as ice-segregation heave.

1/Applicant's Submission, Exhibit Z2, Sect. 3.2.

Conditions causing frost heave are listed as:

(1) Freezing temperature which changes water to ice

(2) Availability of water

(3) Frost susceptible soils

The report presented discussions on engineering approaches to the frost heave problem. These were described under three headings: "Heave Rate Versus Overburden Pressure," "Laboratory Determination of Heave Rate," and "Analytical Study."

With references, it was cited that ice segregation heave rate decreases as the overburden pressure increases. As such, the application of overburden pressure will reduce the frost heave rate and therefore reduce the magnitude of frost heave. As the pressure is being increased, a condition will exist whereby the water will no longer migrate toward the freezing front, but rather will be expelled from it. Such pressure is termed shut-off pressure.

The consultant indicated that the estimated frost heave values in the laboratory, under simulated field conditions, will be conservative, i.e., the estimated value will be much greater than actual field conditions. This was confirmed by the Calgary Test Site of Canadian Gas Pipeline, Limited.

The report stated that, in considering various factors such as the characteristics of the freeze front, variation of overburden pressure, the rate of heat removal, soil consolidation and flow of water, rigouous analytical modelling has been undertaken. Maximum curvature versus time, maximum pipe movement versus time and maximum axial strain versus time have been plotted.

The report also asserted that frost heave in cold permafrost is not anticipated due to the shallow active layer, the low ground temperature and rapid freezeback of thawed soils beneath the pipeline.

In the thawed zone of discontinuous permafrost or in non-permafrost areas, design factors to be considered are

(1) Increased depth of burial

(2) Use of surcharge loading

(3) Replacement of frost susceptible soils with frost stable material

(4) Lowering of the water table

(5) Insulation of the pipeline

ii. Analysis of Submission

The impact of frost heave on the proposed Alcan pipeline is essentially the same as that discussed in the Federal Power Commission's Final Environmental Impact Statement of April 1976, for the proposed El Paso pipeline. The proposed chilled pipeline would contribute to the creation of both types of frost heave by providing the freezing temperature, while the trench would collect water, and fine-grained backfill would provide the frost-susceptible soils.

While the Applicant was correct in stating that a shallow active layer would cause few frost heave problems, it should be noted that the active layer may be increased by construction activities along the right-of-way, which would in turn increase the frost heave potential.

There are several considerations which influence the mitigating effectiveness of increased burial depth or berm surcharging:

(1) Stress on the freezing front will not be proportional to the increased depth or surcharge loading due to the "arching" effects which generally occur where trenches are backfilled.

(2) The surcharge can be removed by erosion and mass wasting.

(3) There are economical and physical limits to the amount of increased depth or surcharge berm which can be applied.

The impact of frost heave on accessory structures related to the pipeline has not been addressed by the Applicant. The structures at the compressor sites would be founded on either shallow or deep foundations, depending on the soil conditions to be encountered. These structures, if founded on frost-susceptible soils, could have serious frost heave effects which would result in cracking of the superstructure and even ultimate failure of the structure.

If shallow foundations are used, the impact of frost heave on the structures cannot be eliminated unless the foundations are placed below the active layer and properly insulated.

At river crossings where pile supports would be required, the effective embedment length of piles must be adequate to resist frost heave force. Otherwise, the bridge would collapse due to uplifting of the pile supports.

iii. Conclusions

(1) The Submission is incomplete in the discussion of all frost heave effects, as it omits the problems of auxiliary facilities.

(2) Except as noted above, the Applicant has properly outlined the conditions under which frost heave problems should be anticipated and has presented adequate design measures to alleviate their effects on the pipeline.

(3) Frost heave is a problem which can be mitigated with proper investigation and design.

d. Erosion and Mass Wasting

i. Applicant's Submission

In the "Geological Hazards" section of the baseline, the Applicant described several types of erosion: thermal, coastal, and riverbank. Less than one sentence per physiographic region is devoted to erosion in the sub-division of that section entitled "Regional Occurrences of Permafrost and Erosion."1/

After stating that overland flow will have been stabilized by the oil pipeline and the highway, the Applicant admitted that "depending on local conditions, erosion could be augmented by the proximity of the proposed gas line to the oil line."2/ A final paragraph on the same page touched upon the seasonal influences of snowmelt and rainfall on erosion.

The mitigations section of the Submission has over one-half page on erosion, wherein it was stated that the Applicant is conducting a field investigation of soils and slopes along the Alaska Highway portion of the proposed route. The results of this study will assist in selecting the appropriate drainage control facilities and should "almost entirely obviate the need for revising drainage control plans in the field...Hence, undersizing and/or misplacement of control structures should not occur."3/ The Applicant listed various types of control facilities to be considered and, later, stated that the appropriate controls would be carried out on all disturbed areas following contruction or as determined by local conditions.4/

The Applicant stated that frost creep and solifluction are probably the most common forms of mass wasting in permafrost environments. The terms "frost creep" and "solifluction" are defined,

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1/Applicant's Submission, Exhibit Z-1, Vol. 1, Sect. 2, pp. 2-76 to 2-73.
2/*Ibid.*, Sect. 3, p. 3-11.
3/*Ibid.*, Sect. 4, p. 4-3.
4/*Ibid.*, Sect. 4, p. 4-16.

indicating that they can occur on slopes as gentle as three degrees and often take such forms as lobes, sheets and terrace-like features.1/

The Applicant very briefly discussed slope stability and presented an outline of the anticipated slope stability problems along the proposed pipeline route. Except for the areas south of the Brooks Range, where the line enters the rolling hills of the Yukon-Tanana uplands, no slope stability problems are anticipated. Side hill cuts and fills will be avoided in the permafrost areas, which tend to become unstable after construction activities and during the thawing process. The Applicant's studies are being continued from the Tanana River crossing east of Tok Junction to the Alaska/Canada border where the proposed route passes through a hilly area; no specific conclusions are made in this area.2/

ii. Analysis of Submission

Erosion is a geological process, primarily caused by water and wind action. Water caused erosion is the greater concern for the proposed project, and the magnitude of this form of erosion increases proportionally to slope inclination. The proposed route would traverse many steep slopes.

Several types of soil found along the proposed alignment are susceptible to erosion. Wind-blown deposits of silt and sand, geologically termed loess, are especially sensitive, as are colluvial and alluvial deposits, when subjected to thermal degradation and/or concentrated water flow.

Construction activities of the pipeline could cause considerable erosion and mass movement unless adequate precautions are taken. Such precautions include drainage control, prevention of significant thermal degradation, and protection of cut-slopes. Even in rolling terrain, ice-rich soils would be very susceptible to erosion and mass movement, since the slope stability in permafrost is very sensitive to the amount of thaw water generated and disipated in the soil.

Whereas the Submission is adequate to indicate that the Applicant has an appreciation of possible erosion problems and has an understanding of the methods to solve those problems, it is too general to permit in-depth analysis.

In the baseline section, several types of erosion were described, but erosion caused by overland water flow, a type of erosion most likely to cause environmental and pipeline-integrity damage, was neglected. This problem was alluded to in the discussion of drainage control facilities. It is appreciated that the Applicant did not have site-specific data available at the time the Application was

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1/Applicant's Submission, Exhibit Z-1, Vol. 1, Sect. 2, p. 2-34.
2/*Ibid.*, Sect. 4, p. 4-4.

submitted; however, some criteria for the design and use of the various erosion and drainage control facilities should have been included.

From a theoretical standpoint, the Applicant's statements that field revisions "should" not be necessary and that "undersizing and/or misplacement....should not occur" are acceptable. From a practical standpoint these statements are optimistic and misleading; construction jobs seldom proceed as planned. There are always field revisions; there are always errors. The goal should be to minimize these.

Mass wasting may take place in various forms such as solifluction, slope failure due to creep of frozen soils, differential ground settlement or consolidation as a result of thaw strain, and slumping of ice-rich fine-grained soils when exposed to external degradation by construction activities.

Two components of the general term solifluction are (i) frost creep -- "the net downslope displacement that occurs when the soil during a freeze-thaw cycle expands normal to its surface and settle in a more nearly vertical direction," and (ii) "solifluction--the slow flowing from higher to lower ground of masses of soil saturated by water."1/ Solifluction occurs only where there is permafrost or deep seasonal frost penetration. The presence of a frozen layer below the transient thaw front, which prevents the downward escape of water, appears to be necessary to promote the relatively fast movement of soil in the thawed stage. Fine-grained materials (i.e., clay or silt) must be present in the upper soil layers, and there must be an ample water supply. The fine-grained soils are necessary to support the migration of moisture by capillarity to the freezing front. In addition, the fine-grained soils experience greater reduction in strength than granular soils because excess moisture is retained more readily.

Since the down slope movement occurs only when earth's surface is seasonally thawed and frozen, the moving layer is relatively thin. Further, the movement is not continuous nor uniform over an entire solifluction area, since thawing does not proceed at the same rate in each sub-area. Each sub-area moves when thaw depth and/or excess moisture develops an instability within the sub-area. Therefore, there is intermittent and erratic movement within the total area. This means that only limited masses are involved at any particular time. Mud flows have been noted from solifluction lobes or terraces that behave as viscous liquids rather than as slides.

Active solifluction occurs on slopes where conditions such as slope inclination, soil stratigraphy, in situ water, and vegetation are ideal to support the process. Alteration of these conditions, by man-made or natural agencies, may possibly inactivate the slope. Conversely, alteration in ground cover, drainage, or other conditions can reactivate an inactive slope.

1/Benedict, J. B., "Downslope Soil Movement in a Colorado Alpine Region: Rates, Processes, and Climatic Significance."

A pipeline installed in the buried or deep buried mode with a cover of three feet or more should not be affected by solifluctuing masses regardless of their rates of movement. However, the work pad which is needed for the construction of the pipeline may undergo significant thaw settlement and thereby possibly fail if maintenance measures are not taken to eleminate the possibility of solifluction by removing poor, undesirable surficial soils. Removal of solifluction lobes will be desirable to eliminate the dished areas, which form directly uphill of lobes and tend to pond water causing local stability problems.

In areas where cuts or transverse slopes must be leveled for work pad installation, all undesirable surficial soils should be eliminated. However, sloughing may occur on the back slope of the cut or at the toe of the work pad, thus requiring simple maintenance work. Thermal erosion; i.e., settlement due to melting of ground ice, may be more severe in some locations than solifluction.

Other forms of mass wasting, due to slope failure, differential settlement, or erosion by surface flow, also require careful engineering analysis of the soil stratigraphy, slope inclination, construction activities, and surface and sub-surface drainage patterns.

It is known that the proposed pipeline will not only encounter bedrock and thaw stable material, but also a heterogeneous mixture of ice-rich soils, frost-susceptible soils, and erodible soils. As such, it will be of great importance for the integrity of the pipeline to analyze each traversed area for potential erosion and mass wasting.

Slope stability in permafrost regions is generally governed by soil type and its long-term strength, slope inclination, dynamic loading, and ground water condition. Surface disturbances, which occur during the construction, will cause thawing of soils in the permafrost regions and the generation of melt water in the soils. If the melting rate exceeds drainage rate, excess pore pressure is generated, which causes loss of soil strength and slope failure. Such events are common in ice-rich fine-grained soils. In thawed soils, if the ground water table is high and adequate drainage does not occur, the same phenomenon is generally found.

It is unlikely that deep seated creep failure will occur along the proposed route unless a very deep cut is made in the frozen ground without adequate stability design.

The impact of mass wasting due to differential settlement of the work pad is also significant. The creation of a deeper active frost layer will cause settlement of the work pad, the magnitude of which will vary depending upon soil type and density, quantity of melt water, and depth of the frozen boundary. Local sections of work pad could fail, causing disruption of the construction or maintenance activities.

Surficial water flow could cause mass wasting in regions where the drainage is restricted to one area and the critical soil tractive velocity of water is generated, thus creating surface erosion. Such cases arise from construction activities.

The Submission is inadequate in dealing with mass wasting and slope instability. These phenomena were mentioned, but were not discussed sufficiently with regard to their effects on pipeline integrity nor the effects of the pipeline on activating them. Mass wasting was not discussed at all and the one method offered to avoid slope stability problems has only limited utility.

Again realizing the Applicant's lack of site-specific data and appreciating the fact that this data is being collected, the Applicant should have discussed the potential problems and provided criteria for the analysis and solution of those problems.

iii. Conclusions

(1) The Applicant has demonstrated an awareness of the potential erosion problems and a knowledge of the measures needed to cope with these problems. The Applicant has not demonstrated an ability to effectively employ those measures.

(2) The Applicant has demonstrated an awareness of the existence of mass wasting phenomena, but has not indicated an awareness that such phenomena offer potential environmental and engineering problems.

e. Seismicity

i. Applicant's Submission

The Applicant provides brief descriptions[1/] of some specific historic earthquakes: notably earthquakes of 1964 near Anchorage; 1937 and 1967 near Fairbanks; and 1968 near Rampart.

The main historical data are summarized in two maps. A seismic zone map[2/] which shows the epicenters of the higher magnitude historic earthquakes and the seismic zones based on their distribution. Importantly, the proposed route does not pass through the highest seismic zone, Zone 4, and avoids the largest concentration of earthquakes in Zone 3. From the Brooks Range northward, the proposed route

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1/Applicant's Submission, Exhibit Z-1, Vol. 1, Sect. 2, pp. 2-73 to 2-75.
2/*Ibid.*, Fig. 2.1.4-6, p. 2-74.

lies in Zone 2 where only moderate damage is predicted as the maximum likely.

An Alaskan seismicity map1/ shows the routes of the Trans-Alaska pipeline as well as the Applicant's proposed route in relation to a plot of numerous historical earthquake epicenters. With the exception of areas around the Yukon River crossing and Fairbanks, the Applicant's route is shown to avoid concentrations of earthquake epicenters. Elsewhere,2/ the Applicant states:

> As a minimum, the pipeline will be designed to withstand the maximum historic seismic intensity experienced along any segment of the route. Seismic risk estimates have been previously developed for the route segment that follows the oil pipeline alignment between Prudhoe Bay and Delta Junction. Applicant is expanding the data base for seismic risk between Delta Junction and the border by conducting a survey of the relationship between seismicity and prehistoric and historic movement along the Denali Fault. Computer modeling of ground accelerations along this pipeline segment from various magnitude earthquakes along the fault is now underway. The resulting data will be used to determine the method of burial for pipe in the zone which might be influenced by fault movement.

ii. Analysis of Submission

The proposed Alcan pipeline route avoids most of the regions of high seismic activity described for the El Paso route in the Federal Power Commission's Final Environmental Impact Statement of April 1976. The Alcan route not only avoids the largest concentration of earthquakes in Zone 3, but does not enter Zone 4--the zone of highest seismic risk. Even so, there has been considerable earthquake activity in Zone 3, especially around Fairbanks, and seismic activity could threaten the integrity of the proposed pipeline system.

1/Applicant's Submission, Exhibit Z-1, Vol. 1, Sect. 2, p. 2-80.
2/Ibid., Sect. 4, p. 4-4.

In addition to the hazards discussed in the Final Environmental Impact Statement, many major catastrophic failures (Seed, 1968;1/ Ohsaki, 1966;2/ Ross, Seed and Migliaccio, 1969;3/) have been observed in recent years due to soil liquefaction in seismically active regions of the world. It is now generally recognized that the basic cause of liquefaction of saturated cohesionless soils during earthquakes is the build-up of excess hydrostatic pressures due to the application of cyclic shear stresses induced by the ground motions. These stresses are generally considered to be due primarily to upward propagation of shear waves in a soil deposit, although other forms of wave motions are expected to occur. During ground shaking, an element of soil undergoes a series of cyclic stress conditions. As a result, the tendency of the saturated soil deposit is to compact and decrease in volume with a resulting transfer of stress to the pore water and an increase of pore pressure. Consequently, the shear strength of soil is reduced. If the duration and magnitude of shaking are large enough that the generated pore pressure is sufficient to cause complete loss of shear strength liquefaction occurs; that is, the soil takes on the characteristics of a viscous liquid mass. On level ground, this will result in the tendency of a weighted pipe to sink or an unweighted buried pipe to float upward. In the case of sloping ground, lateral movement can occur, causing significant damage. This can result in a severe threat to the integrity of the pipeline from both operational and environmental points of view.

The Applicant has not addressed the potential for seismically-induced liquefaction of soils. Further, not a single area along the entire pipeline alignment has been identified for liquefaction potential. The only mention of seismic liquefaction4/ is stated as a probable cause of the slumping related to the 1958 earthquake near Huslia.

Seismic liquefaction cannot occur where any conditions exist which prevent the build-up of excess pore pressures due to the shaking. These conditions are

(1) Clays and some fine-grained silts having adequate cohesion (plasticity index greater than 5) to resist grain movement which could cause excess pore pressure

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1/Seed, H.B., "The Fourth Terzahi Lecture, Landslides During Earthquakes Due to Liquefaction," Journal of the Soil Mechanics and Foundation Engineering, Division A.S.C.E., Vol. 95, No. S.M.4, 1969, pp. 1007-1036.

2/Ohsaki, Y., "The Effects of Local Soil Conditions Upon Earthquake Damage," Proceedings of Specialty Session 2, Seventh International Conference on Soil Mechanics and Foundation Engineering, Mexico, 1969.

3/Ross, G.A.; Seed, H.B.; and Migliaccio, R.R., "Bridge Foundation in Alaska Earthquake," Journal of the Soil Mechanics and Foundation Engineering, Division A.S.C.E., Vol. 94, No. S.M.5, 1968, pp. 1053-1122.

4/Applicant's Submission, Exhibit Z-1, Vol. 1, Sect. 2, p. 2-75.

(2) Very coarse soils, mainly gravels and boulders, which have sufficient permeability so that water flow can occur quickly enough to prevent build-up of pore pressure

(3) Where saturation conditions do not exist (ground water table is at greater depth)

(4) Rock

(5) Frozen soil

These conditions establish criteria for non-liquefiable soils.

Two kinds of material are especially susceptible to seismic liquefaction: (1) unconsolidated, cohensionless soils in the saturated condition and (2) certain under-compacted marine clays that have been uplifted and have undergone leaching. The latter material was a major factor leading to the disasterous slumping during the 1964 earthquake in Anchorage. However, such clays are not likely to occur along the proposed pipeline route.

Thawing of fine-grained soils and/or organic surficial materials with high porosity and/or high ice content may constitute an additional category of susceptible materials unique to high latitudes. These soils may be susceptible to seismic liquefaction on a seasonal basis, following heavy rains, or after a period of thawing induced by removal of an insulating cover or by alteration of surface drainage.

The major point, that the proposed route avoids the most seismically active area near the Gulf of Alaska, is adequately made by the Applicant. The presentation of this information, however, leaves much to be desired. Evaluation of the information presented, for example, is hindered by inadequate documentation. Of ten references cited, eight are not listed in the bibliography1/ and thus cannot be verified.

On the seismic zone map2/ the route of the proposed pipeline is not shown nor the U.S./Canada boundary. This is not a serious oversight, but the relationship between seismic zones and the pipeline would be clearer if the proposed route were shown. Explanation of this figure is inadequate also in that seismic zones are never defined and the source of the map is not fully stated. In addition, one must read a footnote on the map to learn that the absence of epicenters in northern Alaska is at least partly due to lack of

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1/Applicant's Submission, Exhibit Z-1, Vol. 1, Sect. 10, pp. 10-89 to 10-107.

2/*Ibid.*, Sect. 2, p. 2-74.

appropriate equipment to record them; therefore, seismic activity in northern Alaska may be more severe than indicated by this map.

The Alaska seismicity map1/ similarly is not fully explained. It is not clear whether the epicenters shown represent all of the earthquakes detected or only those above some minimum magnitude, nor whether both deep and shallow or only shallow hypocenters are included. Since as many as 4,000 earthquakes may be detected in Alaska each year2/ and the map contains data from five years, it is likely that there has been some selection process. This may seem a minor point, but by selection of data and time intervals, somewhat different maps can be generated, giving rise to the possibility of choosing an alternative that will best support a given objective. For example, compare the Applicant's map (included here as Figure 4) with a similar map3/ prepared for the proposed Arctic Gasline project (included here as Figure 5).

The most serious deficiency is the lack of detailed, quantitative data regarding ground acceleration expected at specific localities. This information must be available before pipe specifications, installation modes, and construction methods can be designed.

In the executive summary4/ and the summary, as well as in the design considerations, the Applicant stated that effects of seismic waves are within the structural capability of the pipeline and that studies will be performed and any necessary remedial action will be taken at fault areas.

The effect of shear waves is discussed to some extent under the heading "Structural Analysis and Design."5/ Faulting, a potentially more serious action, is not pursued in detail. It is not clear from the Submission whether only geological faulting, i.e., bedrock displacement, is considered or if soil movements due to landslides, settlement, or heaving--which can occur at great distances from a geological fault zone but have a similar effect on the pipeline--are also considered. It is not indicated in the exhibits what type of remedial measures are contemplated. The change in buoyancy during potential seismic liquefaction and change in soil pressure due to possible compaction of the overburden due to earthquake activity is also not mentioned.

1/Applicant's Submission, Exhibit Z-1, Vol. 1, pp. 2-80.
2/National Earthquake Information Center, U.S. Coast and Geodetic Survey, Earthquake History of Alaska: Earthquake Information Bulletin, Vol. 2.
3/U.S. DoI, Alaska Natural Gas Transportation System, Final Environmental Impact Statement, 1976, Figure 2.1.1.3-6, p. 84.
4/Applicant's Submission, Exhibit Z2, Sect. 3.3, pp. iii, 2, and 6.
5/Ibid., pp. 25-62.

Under the heading, "Structural Analysis and Design"[1] the Applicant discusses longitudinal strain due to seismic waves. The expression for strain due to an operating earthquake, $E = \pm \frac{V}{4C}$, and a maximum contingency earthquake, $E = \pm \frac{V}{2C}$, are the expressions derived by Newmark[2][3] and are reasonable for straight, long (without end effects) pipe buried in fairly uniform soil. Likewise, the values for soil velocity and propogation velocities[4] appear to be reasonable for preliminary design. Using the Newmark strains computed from the above data, the stresses are within reasonable limits. However, as pointed out by Okamoto,[5] where the rigidity of the ground changes suddenly (rock to soil, permafrost to thawed ground) at discontinuities (underground to above ground, pump stations, valves, appurtanances) or at bends, large bending forces can exist locally. For extreme cases, Shah and Chu[6] calculate bending stresses five times greater than axial stress.

The development of a frost bulb (ring) around the pipe may create size effects, and the critical earthquake induced wave length and amplitude as discussed by Kuesel[7] may be of importance.

In addition to seismic effects on pipeline, but not mentioned in the Applicant's Submission, earthquake design of all above ground facilities must be considered. Critical control facilities must be protected relative to their importance in maintaining the operational integrity of the system during contingency earthquakes.

iii. Conclusions

(1) On the basis of available information, the ground wave velocities used are reasonable. However, the Applicant's discussion of severity of earthquakes is much too brief, considering the importance of the subject. This discussion lacks sufficient clarification,

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1/Applicant's Submission, Exhibit Z2, Sect. 3.3, pp. 25-62.

2/Newmark, N.M., "Earthquake Response Analysis of Reactor Structures," Proceedings of the First International Conference on Structural Mechanics in Reactor Technology, Berlin, Germany, 1971.

3/Newmark, N.M., and Hall, W.J., "Seismic Design Spectra for Trans Alaska Pipeline," Proceedings of the Fifth World Conference on Earthquake Engineering, Vol. 1, 1974, pp. 554-557.

4/Applicant's Submission, Exhibit Z2, Sect. 3.3, p. 49.

5/Okamoto, Shunzo, Introduction to Earthquake Engineering, Chapter 16, 1973.

6/Shah, H.H., and Chu, S.L., "Seismic Analysis of Underground Structural Elements," Journal of the Power Division, June 1969, pp. 53-62.

7/Kuesel, T.R., "Earthquake Design Criteria for Subways," Journal of the Structural Division, Vol. 95, No. ST6, Proceedings Paper 6616, June, 1969, pp. 1213-1231.

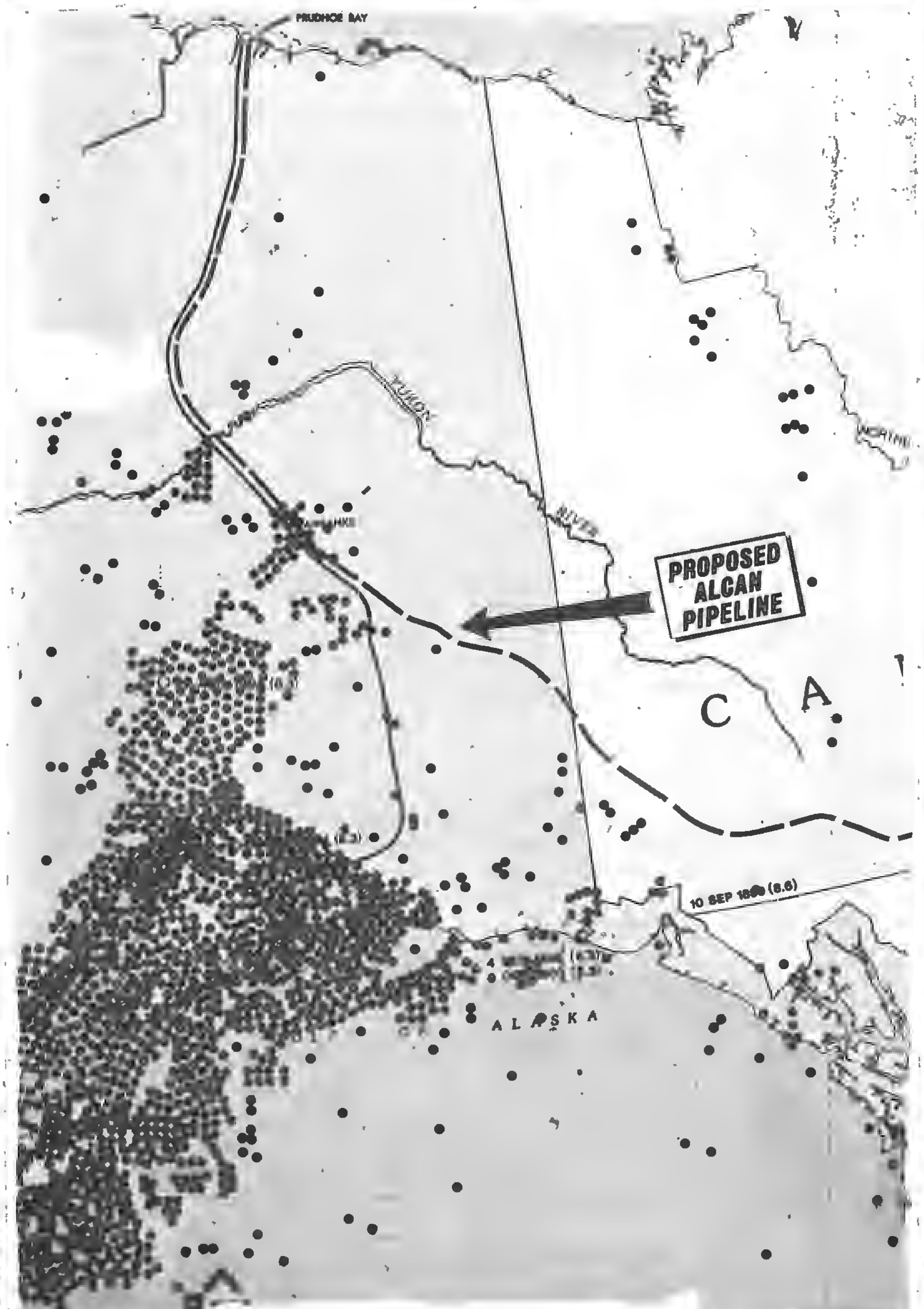

Figure 4 - Alaska Seismicity Map.

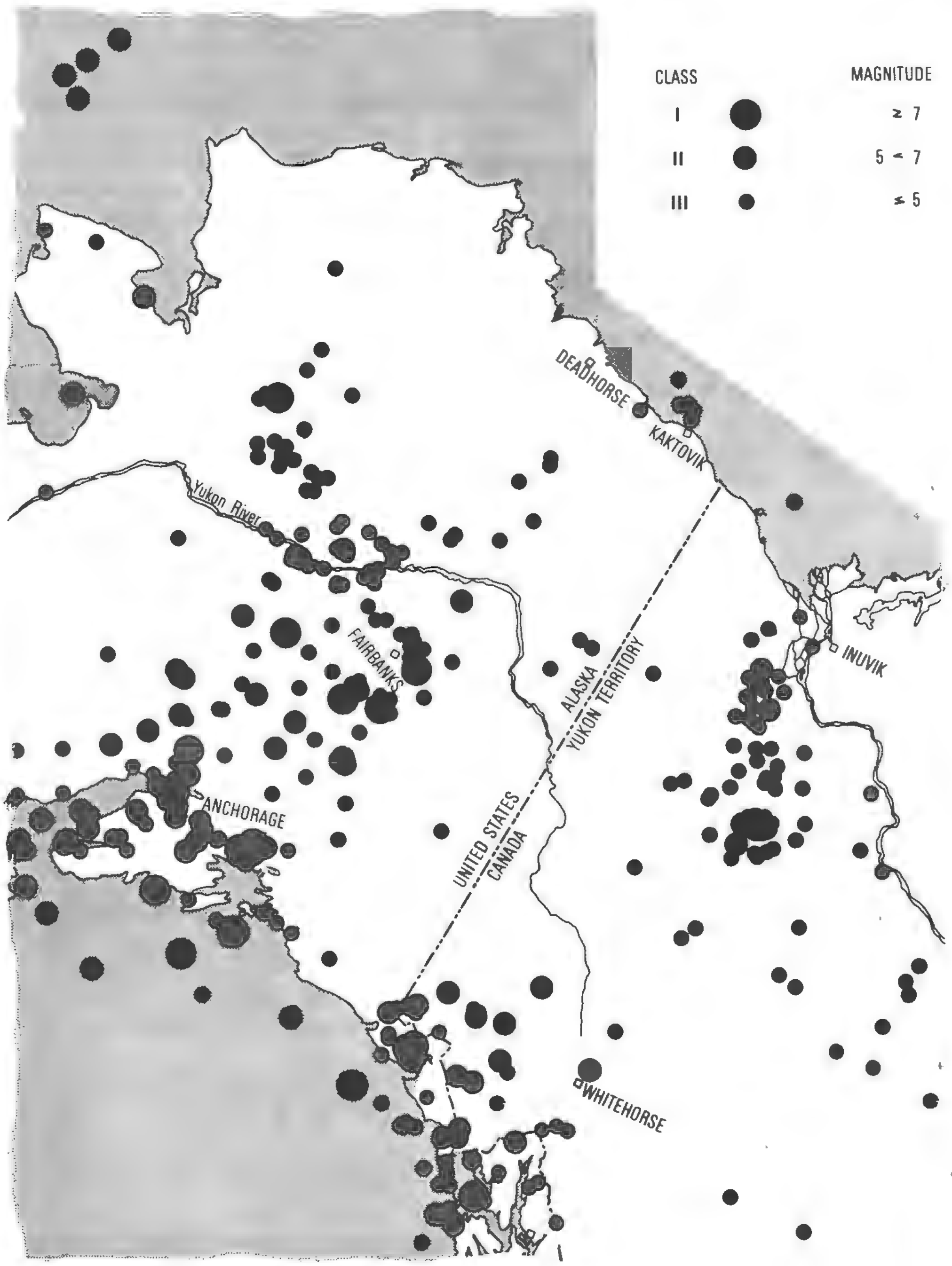

Figure 5 - Earthquake Epicenter Locations, 1899 - 1971.

specifically with regard to:

(a) Details to major historic earthquakes and their effects, and

(b) Maps showing distribution of historic earthquakes.

(2) The Applicant has not considered seismic liquefaction potential. Earthquakes of significant intensity and frequency are known to occur, and it is likely that materials susceptible to seismic liquefaction occur along the proposed pipeline route. The Applicant has not addressed this aspect, either by identifying the location of such materials or be stating that they are present.

(3) The primary deficiency is the lack of hard, numerical data that can be used in pipeline design for specific locations. In addition, the following points should be noted:

(a) Fault movement problems have been superficially treated.

(b) The stress analysis for straight, long sections in uniform soil is in accordance with current engineering practice.

(c) The effect of bends and discontinuities on pipeline stresses during seismic loading, though significant, has not been mentioned.

(d) Earthquake potential for significant damage to the control and operating equipment has not been discussed by the Applicant.

C. ENVIRONMENTAL IMPACTS OF THE PROPOSED ACTION

4. Soils

a. Applicant's Submission

In the baseline section of the Submission, the Applicant provided a simplistic discussion of factors which influence soil development and mentioned briefly the effects of disturbing Arctic soils. These 1 1/2 pages are followed by 4 1/2 pages of generalized soil descriptions for the physiographic regions along the proposed right-of-way.1/

b. Analysis of Submission

The Applicant's baseline data, while interesting, is too general for other than the preliminary planning. The Applicant did not address the potential impacts of the proposed action upon soils and, therefore, did not provide any measures to avoid or mitigate those impacts.

i. Ecological Impacts

Because of poor leaching and very slow biological degradation of organic materials in cold regions, trenching, grading, and borrow pit activities will result in bringing to the surface of the ground relatively nutrient-poor soils. If the revegetation process is to succeed, it will require the addition of fertilizers for rapid establishment and continued growth of most plant species. Erosion is anticipated to continue by various amounts and for various time periods depending on soil types and locations. The ecological impacts caused by erosion may be immediate and long-term, since erosion is usually followed by sedimentation, and both processes have adverse effects on habitat.

Vegetation removal on slopes results in an increased velocity of overland sheet and rill water flow, which accelerates concentration times of storm produced local flooding. Higher velocities of water flow produce greater soil tractive stresses and result in erosion which would not occur at the lesser water velocities sustained under conditions of vegetal soil cover. Though infiltration rates do not alter significantly from those of the undisturbed soil cover, erosion is induced or magnified when overland and rill flows are initiated on unprotected soils. Erosion of incoherent silts in the Fairbanks area and fine sands southeast of the Tanana River Crossing near Tok can be anticipated to be especially severe.

The operation of a chilled gas pipeline will result in warmer or colder mean annual soil temperatures in the vicinity of the

1/Applicant's Submission, Exhibit Z-1, Vol. 1, Sect. 2, pp. 2-52 to 2-59.

pipeline depending on pipeline location, the mean soil temperature at the specific location and the mean pipeline temperature at the specific location (will vary from +5°F to +25°F between compressor stations). In soil-warmed locations, revegetation should progress more rapidly than in soil-cooled locations. Revegetation efforts may need to be repeated after initiation of operation of the pipeline because the plant species and varieties, initially, successfully seeded may not be adapted to the change in the local soil temperature.

Spills of various kinds of fuels, chemicals, and sewage can be anticipated during construction and testing of the pipeline, and these would affect ground waters. Appropriate handling, storage, and disposal methods for such soil and water contaminants should be utilized. Spills which intersect ground waters or streams can contaminate a wide area because of resultant water transport of the contaminant. The rate of movement and amount of dilution of contaminants so introduced in the waters depends on parameters such as amount of dilution waters available, velocities of stream or ground water flows, and levels of turbulence in streams. Biodegradation of organic pollutants can occur as the pollutant passes through the soils while moving downward toward underlying ground waters. If ground water levels are considerably lower than soil surface levels, pollutants may not reach underlying ground waters. If overland flow distances of pollutants are considerable, pollutants can be "ponded" and treated, recovered, or biodegraded naturally without ever reaching streams. This is one reason for locating camps away from streams.

Low temperatures and an absence of appropriate dissolution and dispersion conditions can result in ground water contaminants remaining in the vicinity of the point of contamination for long time periods with very slow biological and dilutional degradation. This results in long-term ground water contamination and is especially troublesome in cold regions.

ii. Engineering Impacts

The various soil types, which will be encountered during the construction activities of the proposed pipeline, may be categorized as organic or inorganic soils, and thawed or frozen soils. The impact of excavation on organic soils as well as frozen soils would generally be more severe than that on thawed soils.

The thickness of organic soil layers (peat and "tundra") is known to range from 0.5 to 2 feet in the Northern regions of cold permafrost to as much as 10 to 15 feet in the Anchorage Area. It is not unreasonable to expect some areas of thick peat deposits along the proposed route. Removal of this sensitive organic layer, which serves both as summer insulation and as a winter chilling heat pump to permafrost soils, will create a deeper active layer and encourage erosion, differential settlement, and subsidence.

The excavated frozen soils will generate higher surface run-off velocities, and drainage provisions will be needed to prevent thermal degradation and erosion of trench and neighboring areas. Special drainage measures would be required where ice-rich soils may generate mud flows after thawing, thus altering natural drainage patterns, encouraging further mass wasting.

The physical and mechanical properties of various locally available soil types should be assessed for engineering suitability as backfill or structural material for the project use. Care should be exercised in writing the specifications for backfill and structural material soils to provide specification compatibility with available materials wherever sound soil mechanics and structural material principles allow.

c. Conclusion

The Applicant's Submission neglected the impacts of the proposed pipeline upon soils and is, therefore, inadequate in this regard.

C. ENVIRONMENTAL IMPACTS OF THE PROPOSED ACTION

5. Environmental Impacts of Water Resources

a. Surface Water

i. Applicant's Submission

The Applicant's surface water baseline discussion was divided in three parts: Surface Water,1/ Distribution of Run-off,2/ and Floods.3/

The Surface Water portion named the hydrologic regions and sub-regions in which the proposed pipeline would be located, provided data on the areal extent and mean annual discharge rate of the Yukon River Basin, mentioned the existence of lakes near the proposed route, and referenced three tables:

Table 2.4.2 - 1	a list of "principal" streams crossed
Table 2.4.2 - 2	a list, with locations, of glacier-formed lakes in the Yukon Region
Table 2.4.2 - 3	a list, with locations but no data, of U.S. Soil Conservation snow course stations

The Distribution of Run-off portion described how run-off data is recorded and provided general run-off data for several streams and drainage basins in the vicinity of the proposed alignment.

The Floods portion described various causes of flooding and seasonal variations of flooding for both the North Slope and the Yukon Region. Also included were discussions of glacial phenomena (discussed in Section C.5.c.), flood-related erosion, and river scour.

The Applicant discussed,4/ briefly, several impacts which construction activities would have upon surface water and surface water effects:

(1) Alteration of drainage patterns

(2) Increased siltation due to increased erodibility of soils

(3) Increased surface flow due to interception of shallow ground water

(4) Ponding

1/Applicant's Submission, Exhibit Z-1, Vol. 1, Sect. 2, p. 2-266.
2/*Ibid.*, pp. 2-266, 2-272, and 2-274.
3/*Ibid.*, p. 2-286.
4/*Ibid.*, Sect. 3, pp. 3-10 and 3-11.

In the sub-section entitled Waste Disposal, the Applicant stated that hydrostatic testing would require 360,000 gallons of water for each mile of pipe in the section being tested and that "no serious impact is anticipated" close to large rivers and lakes.1/

The only impacts on surface water which the Applicant identified for the operational phase of the project were changes in drainage patterns due to frost bulb induced "ridging" of overburden soils and the possible need for more test water should the pipeline fail.2/

ii. Analysis of Submission

The FPC Final Environmental Impact Statement, Volume II, April 1976, Section C.5., discusses water resource environmental impacts for the proposed El Paso gas route from Prudhoe Bay to Gravina Point. The proposed Alcan route diverges from that route at Delta Junction and parallels the Alaska Highway to the Alaska/Yukon Territory Border. That part of the Alcan route lying between Prudhoe Bay and Delta Junction has largely been covered by the above-referenced Environmental Impact Statement.

Large rivers to be crossed between Delta Junction and the Alaska/Yukon Territory Border are the Gerstle, Johnson, Robertson, and Tanana Rivers. Smaller, but important, streams include Yerrick Creek, Tok River, Little Gerstle River, Gardner Creek, and Scotty Creek. Each of the large rivers is primarily glacial fed from the northeast slopes of the Alaska and Wrangell Ranges. The Gerstle, Robertson, and Johnson Rivers are rather wide, short, braided, steep streams with very erodible gravel beds. The Tanana River at the highway crossing, southeast of Tok, is slow moving and has a principally mud bed. The river reaches depths in excess of 35 feet at the Highway Bridge.

Except at major stream crossings where the Haines pipeline utilizes highway bridges, the proposed Alcan route would introduce few new alterations to the present surface drainage on the segment south of Delta Junction. It is not made clear how the Applicant proposed to cross the larger rivers, but if burial in river beds is planned, low water crossings should be relatively uncomplicated except for the deeper Tanana. The Robertson River, shown in Figure 6, is subject to considerable winter icing which remains in evidence until July. An autumn crossing should be readily possible; however, steep river banks near the highway crossing suggest that a crossing downstream in the vicinity of the military road crossing would be preferable.

1/Applicant's Submission, Exhibit Z-1, Vol. 1, Sect. 2, p. 3-13.
2/Ibid., pp. 3-18 to 3-19.

Figure 6 - Robertson River Crossing .

It is unknown how the Applicant proposes to cross this river. Drawing APC-D9-97 indicates that the bridge would be used; whereas, Drawing AFC-B9-21 and Map D21 indicate that the crossing would be upstream, to the west (photograph right) of the bridge. If a buried crossing is proposed, it might be best to follow the military road crossing downstream (out of the picture) from the bridge. (Iroquois photo 8/26/76)

The effects of large-scale gravel removal from the beds of the Gerstle, Robertson, and Johnson Rivers would be minimal. Gravel removals would occur very close to the mouths of the Robertson and Johnson Rivers, so those rivers, which lie almost completely upstream from the crossing points, would not be affected. The Tanana River would receive the major sedimentation impact of these operations, but the relative impact on that stream should be small. Because of the considerable suspended sediment and bed loads which these rivers carry in summer months, it is doubtful that construction activities would create an appreciable impact beyond the local, temporary disfiguration of the borrow areas. Road construction materials have been removed from the Johnson and Gerstle Rivers in the past and the scars have always healed in a year or two because the rivers meander and change channel configurations frequently during the summer months.

Operational effects on all streams along the entire route which are traversed by underwater crossings will result in frost bulb development surrounding the buried pipe. The frost bulb development should have little effect on major confined rivers, but it would have a considerable effect on braided, shallow streams or on the smaller, single channel streams. This situation is illustrated in Figure 7. Figure 7A depicts the stream flow regime before the pipeline is imposed upon it. The frost bulb would initially restrict flow passing through the river's underlying gravels, as shown in Figure 7B, and could possibly extend above the stream bottom (Figure 7C) in winter, thus restricting river flow beneath the ice cover. These effects eventually could result in the forcing of water from the stream and/or the underlying gravels to the surface of the stream and out onto the ice cover. In small streams or in braided, shallow streams, the frost bulb would result in an induced icing problem and could result in a significant portion of the ground water and stream flows being converted to ice during the winter months. This "worst case" is illustrated in Figure 7D. The blockage of stream flow would deprive biological life of its source of dissolved oxygen, which would normally be carried by the stream and gravel flows.

Formation of ice dams could also result in stream channel changes and possibly affect streambank stability if water levels in streams were raised due to such dams. This could affect the integrity of the pipeline where it enters streams.

Repair of the proposed pipeline during the winter at many of the buried stream crossings would be very difficult due to problems of rapid ice formation frequently encountered by repair equipment at that time of year. Highway construction across the Robertson River during World War II resulted in a great deal of equipment being lost to the river during winter construction. More recently, during construction of the winter haul road to the North Slope (Hickel Highway), considerable construction difficulties were reported along the Jack River, in the Brooks Range, because of equipment working in situations of icing and overflow (streamflow confined between river ice and channel bottom breaking out and flowing above the stream ice).

Summer repairs would produce many of the same effects as summer construction, except that the ice bulb surrounding the pipe would make it difficult to excavate, and access to the pipe would be hindered by the surrounding frost bulb.

North of Delta Junction, the Applicant proposed to utilize essentially an extension of the Alyeska work pad. Additional disruptions or rerouting of surface flows should, therefore, be minimal. If snow pads are used, they would not significantly alter surface flows. Snow pads generally melt with their surroundings and do not obstruct spring runoff significantly. Where snow pads have been used on the Alyeska pipeline construction, there exists virtually no visible environmental impact resulting from vehicle activity. However, the use of snow pads precludes summer construction or maintenance operations except as they might be carried out from aircraft or ground effect vehicles (hovercraft). If snow pads are considered, water requirements

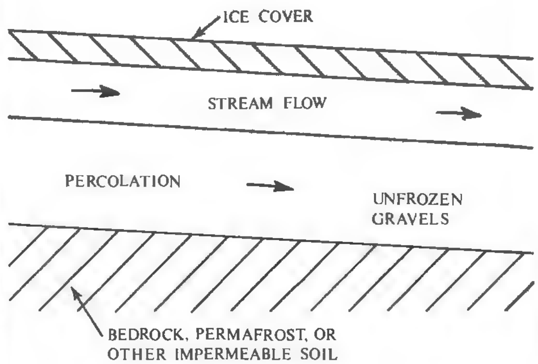

Figure 7A - Unaffected, Prior to Gas Line Construction.

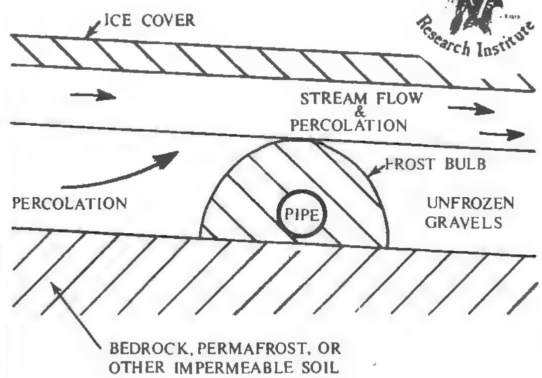

Figure 7B - Disruption of Percolation Flow by Gas Line Frost Bulb.

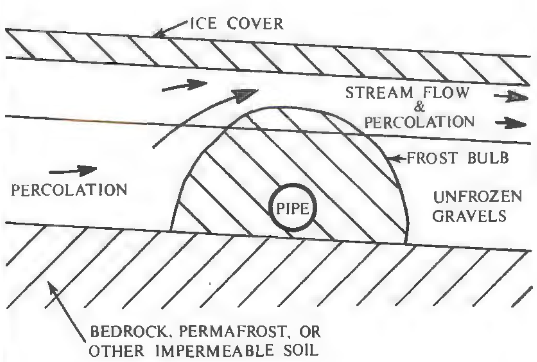

Figure 7C - Disruption of Percolation Flow by Gas Line Frost Bulb with Constriction of Stream Flow.

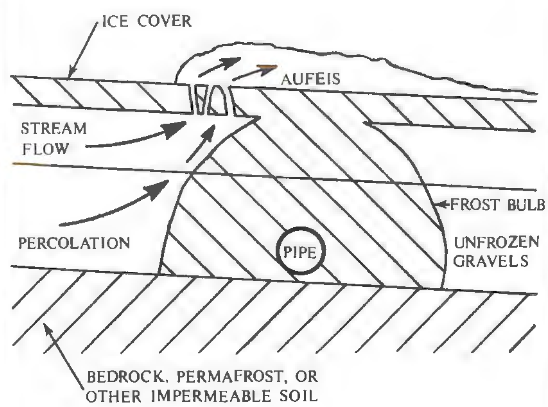

Figure 7D - Constriction of Stream Flow and Percolation in Gravels Beneath Stream Leading to Aufeis Formation on Top of Stream Ice.

Figure 7 - Chilled Gas Line Effects on Stream Flow and Percolation in Gravels Beneath Streams.

may be a limiting factor north of the Brooks Range because of the paucity of available water during winter months. Use of snow fences to gather blowing snow should reduce snow pad water requirements, and snow fences do not have any lasting environmental impact.

Any new roads to be constructed would result in local drainage modifications with a possibility of erosion being induced by channelization of sheet flow. Erosion frequently exists at the downstream end of culverts, where fast moving water is decelerated and on the sides of road fills and cuts.

Water requirements for camps may well exceed the available winter stream flows. Artifically dug ponds approximately 20 feet deep in the outer edges of meandering river channels have been adopted as water supply storage facilities for some of the excess summer river flow on the North Slope. This technique for storage of camp water for subsequent winter use requires that summer excavations be dug in stream beds, resulting in permanent, artificial storage pools in the river bed, thus altering the visual aesthetics of the stream.

With the exception of the Yukon River crossing, where a gas line failure could possibly result in a simultaneous oil line failure, gas line leaks in streams would produce hydrocarbon pollution of water only to the extent that the natural gas constituents are soluble in water. Large failures could produce stream sedimentation and turbidity due to disturbance of the stream channel by large volumes of escaping gas rising up through the stream bed toward the surface of the stream.

iii. Conclusions

(1) The data supplied by the Applicant is sufficient to give a knowledgeable layman a "feel" for the surface water situation along the proposed route. It is insufficient for in depth analysis or for the Applicant's preliminary planning.

(2) The Applicant has totally omitted the impact that surface water may have on the proposed pipeline project, such as increased river scour because of a frost bulb.

(3) It is questionable whether or not the removal of 360,000 gallons of water per mile of hydrostatic test will have a "serious impact" in the vicinity of large rivers and lakes. It is certain to have a "serious impact" in areas with only small streams and lakes.

(4) The Applicant does not seem to fully appreciate the potential environmental impact of the frost bulb on shallow streams.

(5) The Gerstle, Robertson, and Johnson Rivers could provide gravel for the construction of the Applicant's pipeline.

(6) If the project uses the Alyeska work pads as proposed, the Applicant is correct in stating that the additional alteration in drainage patterns would be minimal.

b. Groundwater

i. Applicant's Submission

The baseline discussion stated that groundwater conditions along the proposed route are variable and provided generalized data to support that statement. It also described some of the effects of permafrost on groundwater and gross regional variations of well yields.1/

The only impact of construction activities on groundwater which the Applicant identified (other than on groundwater quality which is discussed in Section C.5.d.) was the interception of shallow groundwater flows due to trenching and grading operations.2/

The Applicant briefly mentioned the potential impact of the operational frost bulb on groundwater flows (this is discussed more fully below.)3/

ii. Analysis of Applicant's Submission

An important aspect of the stream-groundwater hydrology of streams lying north of the Yukon and in other selected locations is that, as surface water ceases to exist with the advent of winter, groundwater provides the only source of available water if storage ponds are not used. The Applicant has not proposed the use of snow pads so, presumably, water will not be required for winter snow pad construction. In addition, the Applicant has proposed to perform construction operations only during those months where surface water supplies exist, at least in sufficient amounts to provide for summer construction camp operations. Withdrawals from groundwater supplies should not be significant in winter during construction, but would probably provide the major source of construction camp water during summer and would be the only source of water for operational camps along the route. Withdrawals would require permits from appropriate State and Federal agencies.

Subsurface drainage would be impacted by the formation of a frost bulb surrounding the operational chilled gas line. Such a frost bulb would create a partial or complete barrier to groundwater movement transverse to the pipeline axis at levels above the bottom of the bulb. If the frost bulb extends downward and intersects the permafrost layer, all groundwater moving above the permafrost would be forced to move above the upper extremity of the frost bulb. If, simultaneously, seasonal frost extends down to and intersects the frost bulb, moving groundwater would generate hydrostatic uplift pressure on the bottom of the seasonal frost layer upstream from the frost bulb and crack its way out to the surface of the ground, thus creating an aufeising problem. (Figure 8). If the seasonal frost is

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1/Applicant's Submission, Exhibit Z-1, Vol. 1, Sect. 2, pp. 2-290 and 2-291.
2/Ibid., Sec. 3, p. 3-11
3/Ibid., p. 3-18

melted (summer), but the frost bulb still merges with the permafrost surface, moving subsurface water is forced above the frost bulb and must move between the surface of the ground and the top of the frost bulb, or, if too much subsurface flow exists in this condition, some may rise to the surface thus creating a spring and the potential for erosion of the unfrozen pipe overburden.

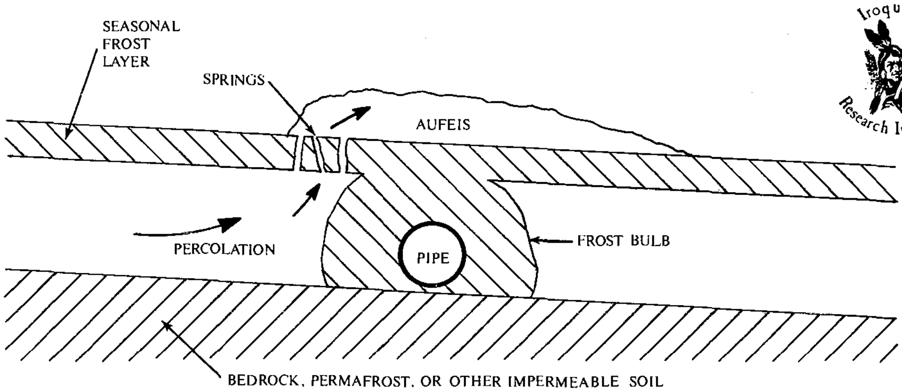

Figure 8 - Groundwater Flow Forced to Surface as a Result of Chilled Gas Pipeline Frost Bulb, with Formation of Aufeis.

Frost bulb existence in fine-grained, saturated soils can induce ground ice formation. This would result in frost heaving of the pipeline and result in a challenge to the pipeline's structural integrity.

Pipeline repairs during the summer season can result in a consolidation of thawed materials with a possible surfacing of ground waters as a result. In many areas, the summer-thawed, active layer where underlain by permafrost, or a segment of the not yet completely thawed active layer, may become saturated. Any consolidation of these existing materials results in the ground surface being forced beneath the water table, and puddles or trenches, filled with water, are created.

Construction trenches extending below the water table at any location result in short circuiting of the passage of ground water, so that ground water flow paths are altered by such trenches.

iii. Conclusions

(1) The Applicant did not address ground water usage and, therefore, did not evaluate the impact of such usage.

(2) The Applicant did not fully analyze the impact of the frost bulb on ground water and does not seem aware that this may affect the integrity of the pipeline.

c. Glacier Phenomena

i. Applicant's Submission

The baseline discussion of glacier phenomena, located in the aforementioned Floods Section, stated that there is a potential for glacial-outburst flooding in the Tanana sub-region, and, after describing why this was so, explained the glacial-outburst phenomena.1/

ii. Analysis of Submission

The Applicant's discussion was incomplete in that there was no discussion of the implications of glacial phenomena, nor how to mitigate the impacts of these phenomena on pipeline integrity.

Outburst floods frequently occur on various Alaskan glacial streams (Knik, Snow, Tazlina, etc., rivers). The proposed Alcan pipeline does not cross streams which have a history of such flooding. This, of course, does not mean that the glacier-fed streams of the route are immune to such flooding. The most significant effect of glaciers on the proposed route would be floods produced by glacial melt during summer. Elevated temperatures occur in summer months of June, July and August, and create significant glacial melt waters. Most glacial streams in Alaska peak from such hot weather induced melt. During these high river flows, the characteristically braided glacial streams erode and meander their braided channels. Pipeline burials would have to be made well beneath such erosional patterns.

iii. Conclusion

The Applicant provided good baseline data, but did not translate it into potential effects upon the proposed pipeline. Glacial phenomena are potentially hazardous to pipeline integrity, and the Applicant has not evidenced an awareness of this fact.

d. Water Quality

i. Applicant's Submission

The Applicant's water quality baseline data, in both the surface water section2/ and the ground water section3/ were presented in gross regional and seasonal generalizations with a few site specific quantifications to illustrate the wide range of variance throughout the proposed pipeline route. Usually, however, concentrations of dissolved solids were described in qualitative terms such as "acceptable," "excessive," and "objectionable" without defining those terms. An 8-page table (Table 2.4.2-5) was included in the surface water section

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1/Applicant's Submission, Exhibit Z-1, Vol. 1, Sect. 2, pp. 2-287 and 2-290.

2/*Ibid.*, pp. 2-274 to 2-284.

3/*Ibid.*, pp. 2-292 and 2-293.

which the Applicant asserted would support numerical data in the text. However, the table is a list of water quality stations and the types of data gathered at each and contains no water quality data.

The Applicant stated that construction activities would have some "minor" impacts on the chemical and physical quality of surface and groundwaters: sediment concentrations would be increased, potential organic pollutants from human wastes, localized impacts from accidental spills.1/

The Applicant proposed to mitigate those impacts by complying with Federal and State regulations and standards for water quality and waste treatment.2/

ii. Analysis of Submission

Pipeline construction, as proposed by the Applicant, would result in a substantial alteration of the soil surface along the work pad additions to the Alyeska line, along any new roads or borrow pits, along the pipeline trench area, and to spoil areas. Each of these must result in some changes to the sediment characteristics of surface water at these locations. In those areas, where heavy erosion results from the removal of the protective, organic mat, flowing water can change its suspended sediment concentration from almost zero mg/liter to in excess of 5000 mg/liter. This would be especially significant in primarily silty or sandy soil areas.

Chemical changes in the water quality would result from spills of hydrocarbons, which reach either groundwaters or surface waters. Camp areas are especially prone to such spills because of the large amounts of hydrocarbons being used and transferred at such points. Tanker truck accidents on the roads cannot be completely avoided during construction or during pipeline operation. Such accidents can result in pollution of either groundwater or surface waters and, conceivably, could contribute to forest fires.

Malfunctioning or overloaded sewage treatment plants at construction or operational camps can result in biological and chemical pollution to the surrounding water. Experience with Alyeska pipeline camps indicates that if camps can be located away from streams or lakes, the effects of spills of various kinds on surface waters can be minimized because of the lag time available to detect and react to such occurrences before the spilled materials can reach the stream or lake. This locating of camps does not prevent problems associated with groundwater pollution.

Recent observations of the Haines, eight-inch pipeline indicate that the long-term erosional and pollutional effects of that pipeline appear to be relatively insignificant in both buried and

1/Applicant's Submission, Exhibit Z-1, Vol. 1, Sect. 3, p. 3-10.
2/*Ibid.*, Sect. 4, pp. 4-14 and 4-15.

and above-ground configurations.

In addition to the inorganic silt loading of streams, the effects of water siltation produced by construction activities would result generally in a reduction in the dissolved oxygen content of the streams involved. This results from the fact that decomposing organic materials are inevitably included with inorganic stream pollution resulting from construction or other erosional activity, and these organic materials have immediate biochemical oxygen demands.

Nutrient loadings in streams also can be increased by improper treatment and disposal of camp sewage and from fertilizers used in the process of revegetation of construction-altered land.

iii. Conclusion

The Applicant's statement that Federal and State regulations would be complied with is not sufficient. Until the Applicant states how it intends to comply, there is no way to judge the adequacy of the plans nor of the ability of the Applicant to effectively use the plans.

variety of uses including gardens, front lawns, and junk yards. Homes also closely abut the present right-of-way.1/ (See Figure 9)

iv. From the Johnson River to the Alaska-Yukon Territory Border, a pipeline distance of approximately 150 miles, 43 individuals have made Native allotment land claims totaling over 3850 acres along the proposed right-of-way.

Figure 9 - Along the Haines Pipeline Right-of-Way

Typical of several points along the Haines Pipeline right-of-way is the coexistence of small communities and the alignment. Alcan proposes to use the existing right-of-way (shown by arrows) to construct its natural gas pipeline between Delta Junction and the Alaska and Yukon border. This photograph faces south near Alcan milepost 550, about ten miles south of Delta Junction. (Iroquois photo 8/26/76)

1/Iroquois Inspection, August 26, 1976.

C. ENVIRONMENTAL IMPACTS OF PROPOSED ACTION

10. Impacts of Land Use

a. Applicant's Submission

The Applicant has provided nineteen pages of land use baseline data giving a brief historical description of land ownership and uses along the proposed pipeline route.1/ In addition, the Applicant has provided general land ownership data on various strip maps. For the most part the discussion of land ownership is general, with the exception of Federal installations and organized communities (Native and non-Native). Transportation and communication facilities are well covered.

The Applicant has provided a detailed qualitative discussion of the impact of the project on the Alaska transportation systems and a very general qualitative description of the impact on subsistence land use. The Applicant further stated: "It can be generally stated that little impact is to be expected upon aesthetic values--except of a temporary nature--, particularly since construction activities will occur in areas already impacted by oil pipeline construction on the existing Alaska Highway-Haines Pipeline corridor."2/

The only mitigation to land use impacts presented by the Applicant is the use of existing utility rights-of-way.

b. Analysis of Submission

Although most of the land use baseline seems adequately covered, the Applicant does not treat the potential problem of private land ownership and use with the seriousness it deserves. The Applicant's operative statement in this regard seems to be "Existing state legal authority provides the condemnation of private lands for pipeline purposes."3/ However, several potential problem areas regarding land ownership have arisen:

i. North of the Yukon River, Alyeska has encountered difficulties crossing several unpatented mining claims.

ii. Individual Native allotment land claims line both banks of the Yukon River in the vicinity of the pipeline crossing.

iii. The Haines Pipeline right-of-way is currently being utilized in some locations by those living along it for a

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1/Applicant's Submission, Exhibit Z-1, Vol. 1, Sect. 2, pp. 2-2 to 2-20.
2/*Ibid*., Sect. 3, p. 3-1.
3/*Ibid*., Sect. 2, p. 2-5

The Applicant's treatment of aesthetics is, at best, casual and superficial. Aesthetics are very subjective. What is visually acceptable to the Applicant may be visually offensive to the individuals who live along the pipeline route. Moreover, the Applicant's statement that the Haines Pipeline right-of-way will be expanded in the direction of the Alaska Highway[1/] is in direct contradiction to the statement that there will be little aesthetic impact along that section of the proposed route. In most areas where the Alaska Highway and the Haines pipeline are in close proximity, narrow stands of trees separate one from the other. Expansion of the right-of-way by 70 feet would reduce this covering vegetation. It is common practice in the "Lower-48" for utilities to plant, not remove, shrubs and trees to minimize adverse aesthetic impacts. The widened right-of-way would also pass through some additional yards, homes, and businesses.

c. Conclusions

i. The Submission is adequate in regard to most of the baseline. The exceptions have been noted.

ii. The qualitative discussion of transportation impacts is inadequate as most of the discussion is baseline data and does not quantify anticipated traffic loads nor individual pay-loads.

iii. The qualitative discussion of impacts on subsistence land use is insufficient.

iv. Aesthetic factors have been accorded insufficient consideration.

1/Applicant's Submission, Exhibit Z-1, Vol. 1, Sect. 1, p. 1-32

C. ENVIRONMENTAL IMPACTS OF THE PROPOSED ACTION

15. Safety and Health Considerations

a. Applicant's Submission

The Submission indicates that Applicant intended to comply with existing safety requirements.

b. Analysis of Submission

Since there is no indigenous population along the Applicant's proposed route, except where the proposed pipeline passes near Fairbanks and a few small communities, safety and health risks apply principally to personnel associated with the construction and operation of the pipeline. However, the safety of the permanent residents of the State is not addressed. Pipeline accidents in the vicinity of homes would provide local potential for fire, explosion, or escaping high velocity gas momentum force disasters; these possibilities have not been discussed by the Applicant.

Where the pipeline passes near or through communities, traffic impact during construction will intermingle local and construction traffic, creating hazards for both. The use of heavy construction vehicles would create major problems in roadway and bridge maintenance for the areas impacted and this in turn would be reflected in increased State and local highway expenditures. Applicant has not addressed these points.

c. Standards, Codes, and Regulations

The principal Federal regulations for safety and health are the Code of Federal Regulations, Title 29, Chapter XVII, Part 1910 (Occupational Safety and Health Administration (OSHA) Standards for General Industry) and Part 1926 (Safety and Health Standards for Construction).

These regulations cover pertinent safety and health topics, the principal ones being

i. Arrangements between prime contractor and subcontractors

ii. Safety Training and Education

iii. Recording and Reporting of Injuries

iv. Personal Protective and Life Saving Equipment

v. Fire Protection and Prevention

vi. Signs, Signals, and Barricades

vii. Safety Practices for Various Trades

viii. Motor Vehicles, Mechanized Equipment and Marine Operations

ix. Blasting and Use of Explosives

x. Compressed Gases

Alaska Statutes, Title 18, Chapter 60, contains the Alaska General Safety Code. This body of law has been amended to conform to the pertinent provisions of OSHA and is as effective as Federal OSHA regulations.

The principal safety and health inspections would be performed by the State of Alaska Department of Labor personnel under an agreement with the U.S. Secretary of Labor.

The State of Alaska has also entered into agreement under the Natural Gas Pipeline Safety Act (PL 90-481) with the Department of Transportation, which allows the State to act as an agent for pipeline safety for interstate pipelines.

Since the Applicant also planned to transship pipe and materials via barges or ships, the U.S. Coast Guard Regulations must be followed.

Motor Carrier and Safety Regulations, DOT, Federal Highway Administration, Code of Federal Regulations, Title 49, Part 390-397, pertains to company vehicles involved in interstate travel and sets specific standards for use.

The Natural Gas Pipeline Safety Act of 1968, (PL 90-481), Minimum Federal Safety Standards for the Transportation of Natural Gas and Other Gases by Pipeline, Title 49, Code of Federal Regulations, Part 192, must be adhered to. The Act and Standards are concerned with the safe construction, operation, and maintenance of pipelines and with the safety of the public.

In addition to the OSHA Construction and General Industry regulations, the Code of Federal Regulations, Title 26, Part 181, dealing with the transportation of explosives, is binding upon the Applicant.

There will also be local safety and health requirements with which the Applicant must comply. Such pertinent local requirements have been promulgated by the Fairbanks-North Star Borough, the North Slope Borough, and by the affected municipalities of Fairbanks, North Pole, Delta Junction, etc., along the proposed pipeline.

The Industry and Underwriter Codes also have application to safety and health considerations in the design and construction of pipeline facilities. Pertinent codes include, but are not limited to:

i. American Concrete Institute

ii. American Gas Association

iii. American Institute of Steel Construction Standards Specifications and Codes

iv. American Iron and Steel Institute

v. American Petroleum Institute

vi. American Society of Mechanical Engineers

vii. American National Standards Institute Code for Gas Transmission and Distribution Pipeline System

viii. American Water Works Association Standards - DoT - Federal Gas Pipeline Safety Standards

ix. American Welding Society

x. National Electric Code

xi. National Electrical Manufacturer's Association

xii. National Fire Protection Association

xiii. National Board of Fire Underwriters

xiv. Underwriters Laboratories

To assure compliance with all applicable Federal, State, local and industry codes and regulations, the following procedures must be observed by the Applicant:

i. Inclusion of, or reference to, applicable codes and regulations in all contract specifications for construction of pipelines and appurtenances.

ii. All supervisory and management personnel must have current editions of the codes applicable to their work and be familiar with them.

iii. As needed, current construction procedures must be updated to correspond with the codes.

d. Safety and Health Programming

Prevention is the most desirable way of mitigating the public safety and health problem. The important features of such a program include physical and psychological screening of potential workers, a safety training program, provision of personal and station safety equipment, healthful working conditions, proper sanitary and rest facilities, adequate and proper medical and first aid treatment.

Since the construction industry is rated among the more hazardous occupations, an organized and systematic Safety and Health Program is essential. Imposed on the program in Alaska are additional factors that are not present in the other states. The harsh natural environment and construction working conditions impose unusual stresses and hazards which must be considered. For example, extended periods of work in subzero weather and darkness, in relative isolation, would be expected to increase the incidence of injuries and phychological illnesses compared to more benign conditions.

There are three basic concepts in the field of System Safety which contribute substantially to its effectiveness. First, hazards in the system must be identified before they are activated, rather than as the result of an accident investigation. Second, attention and effort is focused on assuring that the system is being operated at a minimum level of risk. Third, the data necessary to support management decisions must be developed in order to either assume risks or to modify the system to reduce risks.

After development and establishment of a System Safety Plan, the next essential step is the implementation of an effective training program for personnel. This program would cover such subjects as safe procedures while working in Arctic conditions, Arctic survival techniques, and recognition of hazards and how they may be controlled or avoided. Special attention must be paid to hazards associated with proximity to the Alyeska oil pipeline along much of the route. It should also be noted that, during construction of the Alyeska pipeline, aircraft accidents have been a particularly serious problem.

Safety and health training must be a continuing function for the Applicant and for his subcontractors. Training must reach every level of supervision and each employee.

e. Conclusions

i. The Applicant has not provided details concerning the safety and health of construction personnel during construction, operation, and maintenance of the proposed pipeline.

ii. The Applicant has not provided a specific plan for the protection of Alaskans residing in the vicinity of the proposed pipeline.

iii. The Applicant has not provided nor evidenced an understanding of the need for a detailed System Safety and Emergency Plan covering all aspects of construction, testing, operation and maintenance of the proposed pipeline.

D. MEASURES TO ENHANCE THE ENVIRONMENT OR TO AVOID OR MITIGATE ADVERSE ENVIRONMENTAL EFFECTS

1. Pipeline System

a. Design

i. Alignments

(1) Applicant's Submission

Applicant proposed to follow closely the Alyeska alignment from Prudhoe Bay to Delta Junction and the Haines pipeline right-of-way from Delta Junction to the Canadian Border.[1]/[2]/

(2) Analysis of Submission

Along much of the Alyeska pipeline, where ice-rich permafrost soils exist, that pipe is elevated above ground on Vertical Support Members (VSM) so that the hot oil pipe does not introduce heat into the thawable soil. Thermal expansion and contraction of the elevated pipeline would be difficult, if not virtually impossible, to eliminate. Alyeska chose a trapezoidal, zig-zag pipeline alignment to allow its pipe to flex transversely to the pipeline thus accomodating thermal contraction and expansion. This trapezoid pattern is illustrated in Figure 10, a photograph of the portion of Alyeska's pipeline on the North Slope which was constructed with a snow work pad.

Along those sections of the Alyeska pipeline where that pipeline is elevated on Vertical Support Members (VSM), the Applicant proposed that its pipeline would have a trapezoidal alignment, closely paralleling that of Alyeska. Though the Alyeska alignment configuration was selected to provide for expansion and contraction of the elevated sections, the Applicant's pipeline is proposed to be buried for virtually its entire length. Its expansion and contraction will, therefore, be confined to longitudinal strains because of the constraints of the trench. In those segments of the Alyeska pipeline where VSM exist, there are approximately six or more side bends per mile of pipeline which are devoted exclusively to providing the trapezoidal, zig-zag expansion-contraction configuration. In several of these areas, the Applicant's route could be appreciably straightened with only marginal increases of work pad fill beyond what would be required to follow closely the details of the Alyeska pattern. In other situations, the trapezoidal, zig-zag Alyeska pipeline configuration diverges widely from a straight alignment, so that drainage from the area between the Alyeska and a straight Alcan alignment could be quite poor, thus possibly creating stagnant lakes. Two situations

1/Applicant's Submission, Exhibit Z2, Sect. 1, Drawing No. APC-B9-1 to APC-B9-25.
2/1" = 1000' Strip Sheets No. APC-D9-1 to APC-D9-117.

Figure 10 - Alyeska Pipeline Trapezoid Pattern

The zig-zag, or trapezoid, pattern shown here was designed to allow the Alyeska pipeline to thermally expand and contract. In the above ground mode the oil pipeline is supported by pairs of Vertical Support Members (known as VSM bents). The cross-piece connecting the two VSM has a Teflon coating, as does the immediate pipe support. This allows the pipeline to expand or contract and still be supported. This photograph taken in an easterly direction from Alcan MP 125, also shows the transition from an area where Alyeska used a snow work pad to an area where a gravel pad was used. In right center is a dust cloud caused by traffic on the haul road which converges with the pipeline from the right. The pieces of pipe on the tundra were left after last winter's work and are planned to be removed when work resumes this winter. (Iroquois photo 8/25/76) are indicated in Figure 11. Trade-offs between gravel quantities and availabilities, drainage possibilities, and construction, maintenance, and operation of the straight vs. zig-zag configuration can be evaluated to determine the most feasible alignment.

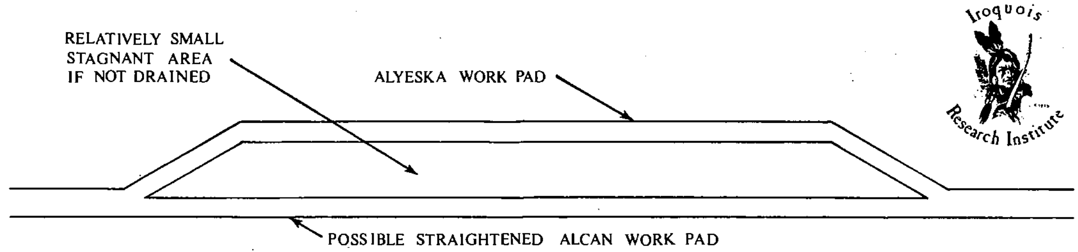

Figure 11A - Simple Trapezoid.

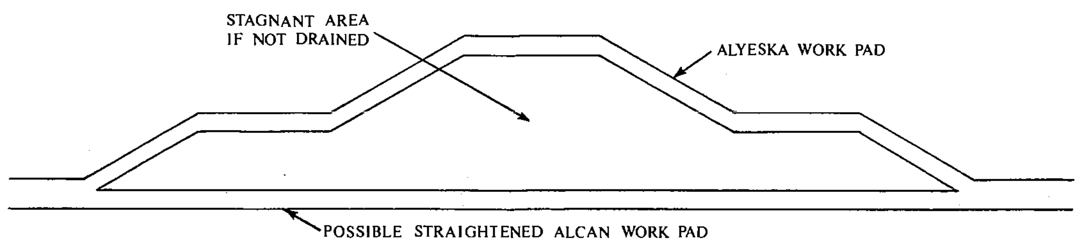

Figure 11B - Multiple Trapezoid.

Figure 11 - Implications of Possible Straightening of Alignment of Alcan Pipeline.

Along much of the proposed parallel Alyeska-Alcan right-of-way, and especially in the trapezoid alignment areas, the Applicant must widen the existing work pad. This work pad widening is of significant proportions in side hill non-thaw stable locations, areas which have required Alyeska to elevate its pipe in traversing.

The Alyeska alignment was selected by that company on the basis of several constraining factors, one of the most important being the elevated temperature of the oil to be transported through the pipeline. When the final Alyeska alignment was chosen, compromises were made to accommodate environmental concerns of various kinds as well as other public and private factors. However, in every case, the chosen route was not allowed to compromise the physical support (integrity) of a "hot" pipeline. Use of the Alyeska alignment by the Applicant would certainly avoid the reopening of non-engineering issues which dictated the present Alyeska alignment. It would, as the Applicant stated, also minimize additional environmental damage. This would, however, be true only if the alignment proximities can be as close as they are indicated in very cursory fashion by the Applicant.

Both the Alyeska pipe and the proposed Alcan pipe would be extremely large pipelines both in size and in throughput. The distances between shut-off valves on both pipelines average 13 to 15 miles, thus a considerable quantity of product could be spilled by the Alyeska pipeline or blown off by the Alcan line or by a combination of these two failure events. The Applicant has not addressed the matter of increased disaster potential created by the close proximity of the two massive pipelines. The Alyeska pipeline is not now operational, so the effect of an act of vandalism or sabotage is not of present concern. However, with so much of that pipeline elevated, the operational sabotage possibility is certainly much greater than if the pipe were below ground. (The punctuated fate of road signs in Alaska may foretell the future of an elevated pipeline.) Since the possibility of man-induced damage of the Alyeska pipe is not remote, the closeness of the proposed gas line would compound the potential for disaster.

(3) Conclusions

(a) The Submission provided no evidence that the Applicant evaluated any alternative alignments. There are other alignment possibilities within the proposed route corridor which may be preferable from environmental, engineering, and economic viewpoints.

(b) The energy levels contained by the two operational pipelines in close proximity to each other certainly present the potential for serious disasters. The explosive and fire damage potential of the gas pipeline appears to be an unknown. The addition of the Alcan pipeline changes the disaster conditions which could exist along the right-of-way from those which were deemed acceptable for the Alyeska pipe by itself.

D. MEASURES TO ENHANCE THE ENVIRONMENT OR TO AVOID OR MITIGATE ADVERSE ENVIRONMENTAL EFFECTS

1. Pipeline System

a. Design

ii. Communications and Pipeline Control System

(1) Applicant's Submission

Alcan Pipeline Company stated1/ that the pipeline would be controlled from a Master Control Center located at Fairbanks, Alaska. All data would be relayed to the Fairbanks Master Control Center over a microwave-radio link, while control of the compressor stations and metering stations would be exercised remotely from the Master Control Center through the same microwave-radio link. The Applicant's Submission described briefly both the microwave communications system and the supervisory-control and data acquisition system.

The Applicant stated that 48 dedicated microwave channels would be required for control of the proposed pipeline. These channels would be used for voice communications; for remote control of the pipeline operation from the Master Control Center at Fairbanks; and for transmission of data, obtained from sensors along the pipeline, to the Master Control Center.

The Applicant also stated that "between Prudhoe Bay Metering Station and Delta Junction, the microwave backbone communication system serving the Alyeska Pipeline . . . will provide the communication channels required."2/ An additional microwave system with the required dedicated channel capacity would be constructed by RCA Alaska between Delta Junction and the Alaska/Yukon Border Metering Station to provide communication to this area.

(2) Analysis of Submission

The Applicant's description of the entire Pipeline Communications and Control System is brief and general. Operational implementation is not discussed and practically nothing is said of operating contingency plans in the event of partial or catastrophic failures. Thus, it is not possible to evaluate operation of the system in various contingency modes, because the intended system may or may not have the flexibility to properly cope with these various problems.

1/Applicant's Submission, Exhibit Z2, Sect. 5, pp. 1-3.
2/Ibid., p. 1.

(a) Communications Link

The Applicant has indicated that the existing microwave backbone communications system serving the Alyeska Pipeline would be utilized. However, RCA will have commitments not only to the Alyeska Pipeline, but to other companies and villages along the Alyeska Pipeline, as well. There is no indication in the Submission that the additional dedicated 48 channels will be available when required by the Alcan Pipeline Company.

(b) Data Logging

The section title implies that the planned Alcan control system is a data acquisition system, but no detail of the acquisition system is given, no mention of the type of data nor the quantity of the data which will be acquired is given, and, most importantly, no discussion is given to indicate that the data to be obtained will be sufficient to detect failure or anomalies in the operation of the pipeline. Also, no analysis of the data transmission link is given to show that data can be transferred over the communications link at a sufficient data rate to detect existing or impending failure in time to prevent catastrophies along the pipeline.

(c) Monitoring and Control

The Alcan Pipeline Company Submission says very little about what control functions at each station would be exercised remotely from the Master Control Station, and nothing about what data would be monitored and collected. Indeed, the Applicant did not even indicate automatic control of the pipeline, but has only implied automatic control by the size of the digital computers proposed. The Submission lacks the following information necessary to evaluate the adequacy of the monitoring and control system: what data are telemetered to the Master Control Station, what data are recoded locally, and how test data are used in the control function; the degree of control exercised over the remote stations from the Master Control Station; the degree of control exercised at each remote station by the local controller and the levels of operation attainable under local control; the methods of measurement used to obtain the data; the type and operation of the electronic equipment used to convert the measurement to electrical signals for transmission over the communication link; and the type of equipment used to remotely exercise control over the pipeline.

(d) Failure Modes

The data communications and supervisory control is critical to safe operation of the pipeline. The potential modes of failure must be analyzed before the system is implemented so that adequate control safeguards are built-in rather than added on. The Applicant has not discussed failure modes which might occur and no failure mode analysis is offered.

(i) Catastrophic Failure

It is conceivable that a catastrophic failure could occur in which both the pipeline is damaged and the communications link is interrupted. Such a failure might occur from natural causes, such as an earthquake or landslide; man-caused failures might occur from an act of vandalism or sabotage.

Local controls upstream and downstream from the failure must be able to recognize the faults and initiate action to close the pipeline to avoid feeding the failure with flammable gas. Since communications with the affected station would have been interrupted, contingency plans must be initiated automatically as a result of some pre-planned syllabus with no or little additional stimulus or data.

The Submission does not indicate how Applicant proposed to cope with catastrophic failures.

(ii) Minor Failures

More likely, but equally important as a catastrophic failure, is a minor failure which could grow to catastrophic proportions. Such an event could be the failure of a valve or pump control, etc., which in turn damages safety or operating equipment.

The normal prevention of catastrophic results from minor failures is by the interlocking of controls through sensors and by redundant controls. The description of the system presented in the proposal is insufficient to judge whether such protection would be incorporated into the system design, much less whether or not any designed-in protection would be adequate.

(iii) Loss of Communication

During a communications failure, the loss of control of the pipeline from the Master Control Center could itself be catastrophic. Contingency plans must provide alternate methods of monitoring and control, even if at a much reduced data rate. The preferable alternative would be to establish communications through an alternate channel route (e.g., through an unused voice channel or a long-haul radio link). Otherwise, the affected system should go to local automatic control with local sensing of pipeline operation. It might also be necessary gradually to reduce the system operation. Prolonged failure of the communications link possibly might indicate major trouble along the pipeline, thus providing increasing opportunity for failure.

Another problem with failure of the communications system is that of remote sensing of the failure. This can be accomplished by any of several methods, the most thorough being detection of an increased error rate in replies to a transmitted message, and the least reliable being simple detection of the microwave channel carrier signal. However, the Submission offers no discussion of any method to detect loss of communication, and states only that "station operation (will continue) under dynamic local control in the event of a communication failure between the Master Control Unit and the station."1/

The above statement regarding local control is an inadequate treatment of a very complex response to a very important failure. It is important, due to the range of possible accompanying failures (e.g., pipeline break or wrong vent or valve arrangement) and complex in its responses (continual operation with the fault, partial reduction of operation, or complete loss of operation with associated problems of restart after correction of the fault.) Consideration of such an important factor requires a detailed discussion which Applicant has not provided.

(e) Protection of the Communications Systems

Data communications in the Supervisory Control and Data Acquisition System should be protected to assure reliable communications. The Submission omits any discussion of such protection. Examples of protective methods are given below:

(i) Back-up Systems

Certain critical portions of the operating and monitoring system should be duplicated to increase reliability. These are sensing of critical parameters such as pressure and flow levels; valve and vent positions, etc.; and key data transmission elements such as the microwave communications link transmitter.

In addition, Applicant has not mentioned the possibility (and desirability) of benefitting from alert data from the separate Alyeska Communications and Control System in common-risk situations.

(ii) Error Checking

Message security is required to ensure error-free operation of the pipeline. Security may take the form of either parity (or error) checking, or, even better, reflecting the received message for confirmation of the message at the transmitting end, or both. If the receiver reflects the received message back to the transmitter, either an execute message with parity would be transmitted upon confirmation of the message or the message would be repeated if the reflected message were in error. After the message is repeated a limited number of times without success, the communications-failure mode of operation would be entered.

1/Applicant's Submission, Exhibit Z2, Sect. 5, paragraph 5.2.2.

(iii) Communication Failure

In the event of pipeline shut down or reduced operation due to a communication failure, the pipeline requires protection during restart or during continued reduced operation to avoid detrimental effects. The local control system design must include reduced operation and restart protection. No discussion of this is included in the Submission.

(iv) Contingency Planning

In the event of a failure of the communication system, planning to an emergency cut-off time line is important for operation in the absence of communication. The condition of a station with a failed communication system may be unknown to the upstream station, and, possibly, in a very abnormal situation, the station condition may also be unknown to the downstream station. With these possible unknowns, automatic pipeline operation cannot proceed at a normal rate for an indefinite period because of the danger involved in, for example, continued operation of a damaged turbine. This point is omitted from the Submission.

(f) Operator Interaction and Alarms

Another area not addressed in the Submission is that of the function of the operator. Automation of the pipeline operation does not eliminate the need for an operator to monitor the system, with the ability to intervene in the event of a situation not programmed in the automatic controller. Examples of such events include failure of the electronics equipment used in the controller, changeover to new or different components for the automatic control system, or maintenance and testing of the automatic control equipment.

Part of the operator monitoring function is to respond quickly to emergency situations. This requires that the operator be alerted to the occurrence of a condition which requires his action, and, if possible, to the impending occurrence of an emergency situation. Obviously, different alarm levels should be given for impending emergencies and the occurrence of emergency situations. No mention is made in the Submission of operator alarms.

The level of operator control, the level of automation, and the conditions for which operator action will be required were not discussed by the Applicant. In order to properly evaluate the safety of the pipeline operation, more detail of the level of operator interaction, the conditions of alarms and the control alternatives available to the systems operator would have to be known.

(3) Conclusions

The Applicant's Submission is insufficient to evaluate either the effectiveness or the suitability of the planned communication and control systems. In particular, the Submission is lacking:

(a) A detailed implementation plan for the pipeline communications and control system;

(b) A description of control system operation;

(c) Analysis of failure modes in the communication system and the control system;

(d) Discussion of operation during a failure of the control system and/or the communication system;

(e) Discussion of provisions for safety to equipment and personnel during a failure of either system;

(f) Description of the operator function and control available to the operator during an emergency or abnormal situation.

D. MEASURES TO ENHANCE THE ENVIRONMENT OR TO AVOID OR MITIGATE ADVERSE ENVIRONMENTAL EFFECTS

1. Pipeline System

a. Design

iii. Engineering

(1) Facilities

(a) Compressor Stations

(i) Applicant's Submission

The Applicant proposed to construct 15 compressor stations spaced at intervals such that the horsepower requirements at each station would be about equal. The stations would operate automatically and would be controlled remotely. The machinery at each station includes gas turbines using gas from the line as fuel One 26,500 horsepower turbo-centrifugal compressor unit would be installed at each station. The turbo-compressor would be equipped with inlet and exhaust silencers, an explosion proof electrical system, and an automatic control system.

The gas cooling system would consist of a two-stage, gas turbine driven propane compressor, electrically driven condensers, and a heat exchanger. Electrical power would be produced with three turbine drive, 480-volt, 3 phase, 60 Hertz alternators, each of 800 Kilowatt capacity. One of the three units would be for standby service. Dual fuel systems would be provided to allow liquid (Diesel) fuel to be used as an alternate to gas.

Auxiliary equipment and systems include:

1. Automatic control
2. Hot water/glycol heating system
3. Instrument and utility air system
4. Remotely operated valves
5. Gas scrubbing system
6. Fresh water system
7. Sewage and waste disposal system
8. Corrosion prevention system and techniques
9. Fire fighting system

10. First aid system

11. Housing structures

12. Foundation pads of gravel

13. Communications system

14. Fuel, propane, and general storage systems

15. Living quarters

Main-line meter stations would be located at Prudhoe Bay and at the U.S./Canada border. A block valve would also be located at the border. A sales meter would be located in the service line to Fairbanks.

Each compressor station is planned to occupy a 700 feet x 900 feet plot or approximately 14 1/2 acres. The main-line meter stations would occupy areas 110 feet x 210 feet or about 1/2 acre each. The Fairbanks meter station would occupy an area of 100 feet x 105 feet or 1/4 acre.

The proposed schedule of operations show only partial operation during 1981 and 1982, reaching full operation in 1983. Consequently, chilling capacity is not required in all stations during the 2-year build-up period of 1981-1982. Thus it is contemplated by the Applicant that compressor stations would be brought "on line" in accordance with the schedule shown in Table 1.

The Applicant also stated that noise, exhaust emanations and temperatures would be controlled within prescribed and safe environmental limits.

(ii) Analysis of Submission

A report by EBA Engineering Consultants, Ltd., stated:1/

> From Delta Junction to the Yukon Border the pipeline encounters fairly well drained sands and gravelly soils which are generally more stable than the organic ice-rich silts insofar as thaw settlement is concerned. Hence, it appears feasible to leave the pipe unchilled from Delta Junction to the Yukon Border. However, more detailed studies on the possible adverse effects of the discontinuous and isolated permafrost

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1/EBA Engineering Consultants, Ltd., "Preliminary Thermal Input Parametrics for Flow Studies in Gas Pipeline from Prudhoe Bay to the Yukon Border via Fairbanks," May 1976, Section V, Enclosure to Letter to Foothill Pipe Lines, Ltd., dated May 25, 1976.

TABLE 1 - COMPRESSOR STATION START-UP SCHEDULE

Station	Mile Post	On line date for					
		compressor			chiller		
		1981	1982	1983	1981	1982	1983
1	43.5			x			x
2	83.7	x			x		
3	118.6			x			x
4	157.7		x		x		
5	210.8			x	x		
6	261.9	x			x		
7	305.9			x	x		
8	355.0		x		x		
9	400.7			x	x		
10	442.6	x			x		
11	497.4			x	x		
12	543.6		x		x		
13	590.3			x	x		
14	639.4	x			x		
15	684.1			x	x		

> zones on the unchilled pipeline will be required in order to decide on an unchilled pipeline from Delta Junction to the Yukon Border. For the preliminary gas flow studies, it is recommended that the entire pipeline from Prudhoe Bay to the Yukon Border be considered as chilled.

This quotation leaves some doubt regarding the installation of chillers at Stations No. 12, 13, 14, and 15, which are located between Delta Junction and the Yukon Border. It appears that with some relocations to higher ground than that presently occupied by the Haines pipeline right-of-way and with addition of some sections of elevated pipeline, the necessity for chilled pipe from approximately the location of the Tanana River crossing north of Delta Junction to the Yukon Border might be eliminated. Further soils information may also indicate a lack of necessity of elevating an unchilled pipeline on this part of the route.

The Applicant displays a considerable knowledge of compressor station design; however, there are certain omissions which should be considered. They are discussed in the following paragraphs.

Federal Regulations which apply specifically to many aspects of station design, construction and operation are

1. Title 49, Part 192, Subpart D, Code of Federal Regulations, "Transportation of Natural Gas and Other Gas by Pipelines: Minimum Federal Safety Standards."

2. Title 29, Part 1926, "Occupational Safety and Health Regulations for Construction" and Part 1910, "Occupational Safety and Health Standards."

3. Title 18, Chapter 1, Part 12, "Inspection of Project Works With Respect to Safety of Structures."

The Applicant proposed to use one large centrifugal compressor and gas turbine prime mover in each station. Consequently, down time on either the prime mover or the compressor would have a considerable effect on the quantity of gas delivered. The Applicant intended to minimize down time by establishing a quickly responsive maintenance organization and a ready supply of spare components and parts. In addition, a condition monitoring system with remote readouts is intended. Considering that no fall-back unit is available in the event an outage of the compressor occurs, the monitoring system should be highly sensitive and reliable, and its signals should have a meaningful relationship to the machinery's health. In other words, the monitoring system must be able to detect the onset of failure before it occurs and sufficiently beforehand so that remedial measures can be taken.

Although much development has been and is being done to produce instrumentation which will provide the quality of monitoring required, it is not presently available, at least in the high quality level of the performance required. For example, if an aircraft-type turbine converted to other than aircraft service is used, it is well documented that major failures of blades in the high pressure turbine and/or liners in the combustors are possible within a few thousand hours of service. The compressor drive turbine would operate continuously, which means 8760 hours per year. Consequently, a major failure, requiring shutdown of the turbine for major repairs, must be planned for on the basis of one or two such outages per year. No commercial instrument is presently known which will detect automatically the onset of blade or liner failures. On the other hand, a periodic, visual inspection by experienced service personnel coupled with instrument data would provide highly satisfactory estimates of the remaining life of these highly critical parts. Such inspection information, obtained and analyzed in a systematic manner, would aid greatly in reducing major system failures.

The gas turbine prime mover would produce noxious gases and vapors, and, at times, objectionable particulates in the exhaust. The gases and vapors are

1. Sulfur oxides, which result from the burning in the turbine combustor the small amounts of sulfur existing in the gas used for turbine fuel.

2. Nitrogen oxides resulting from the oxidation (burning) of some of the nitrogen component of the air passing into the turbine's combustor.

3. Water vapor (steam) resulting from the combustion of the hydrogen fraction of the fuel gas.

4. Carbon dioxide resulting from the combustion of the carbon fraction of the fuel gas, except for that which is only partially burned which forms carbon monoxide instead of carbon dioxide.

5. Particulates resulting from partially burned hydrocarbons. Such material is essentially nonexistent when burning fuel gas, as in normal operation; however, if and when fuel oil is used for starting from cold or for other purposes, some hydrocarbons may be only partially burned or not at all. Such inefficient combustion will usually cause the hydrogen to burn before the carbon fraction of the fuel molecule, causing either carbon (soot) or carbon-rich molecules to appear in the exhaust giving it a grey color.

The more noxious vapors need to be monitored. If unsatisfactorily high in quantity, adjustments are required to bring them within satisfactory limits. These limits are imposed by State and Federal governments. They apply to unburned and partially burned hydrocarbon vapors, oxides of nitrogen, sulfur compounds, carbon monoxide, and any solid particles present. Although water vapor is a necessary product of gas combustion, under the proper atmospheric conditions, it can be troublesome in that it may condense from the vapor phase to form a persistent fog. With extremely low temperatures, ice fogs may be produced. Exhaust components (sulfur compounds) also have some corrosive effects such that exhaust stacks should be located so the exhaust gas would not contact radio antennae.

Gas turbines are noisy, especially in the higher frequency range. Because of this high frequency, the noise level can be fairly easily controlled with silencers placed in the intakes and exhaust, by lining the machinery room with anechoic material, constructing the walls to have high mass and mounting the turbine and its foundation on sound isolators.

Noise levels are usually specified at a value such that it will not be deleterious to humans on a continuing basis. For an eight-hour period of exposure, the maximum level is specified at 90 decibels,1/ measured on the "A" scale of a standard sound meter at slow response.

Construction and operation of a natural gas compressor station is hazardous because of the flammability, high energy content and volatility of natural gas. These characteristics are greatly accentuated when it is stored and pumped at high pressure. The use of propane as a refrigerant does little to add to the already high hazard level accompanying the handling of pressurized natural gas, except that the propane is heavier than air and consequently will not dissipate as rapidly, tending to concentrate in low spots. On the other hand, it is slightly less volatile than natural gas, which is helpful.

Other aspects of this subject are discussed under Analysis of Public Safety, Section C.15.

(iii) Conclusion

The design effort of the Applicant has not proceeded to a point where the many details of station design can be stated. The Submission does indicate an awareness on the part of the Applicant of the problems attendant to the detailed design. Adherence to the various codes and requirements of the State and the Federal governments should provide much of the guidance required.

1/"Federal Register," Vol. 39, No. 125, June 27, 1974, Subpart G, Section 1910.95, Ch. XVII, p. 23596.

D. MEASURES TO ENHANCE THE ENVIRONMENT OR TO AVOID OR MITIGATE ADVERSE ENVIRONMENTAL EFFECTS

1. Pipeline System

a. Design

iii. Engineering

(1) Facilities

(b) Temperature Maintenance

(i) Applicant's Submission

The Applicant proposed a buried pipeline (except for certain river crossings) with the gas chilled to temperatures ranging from 5°F to 25°F initially (1981) and finally (by 1983) leveling off at uniform station discharge temperatures of 25°F.1/ The temperature would be maintained through the use of refrigeration equipment stated to be housed in the compressor buildings although no plan of such installations has been furnished. Neither has a plan been submitted indicating how the gas temperature would be controlled at the desired value.

The Applicant has presented a well authenticated discussion of heat transfer in Alaskan soils.2/ This discussion indicates suitable capability to calculate soil temperatures within the state-of-the-art and to predict reasonably well the resulting loads on the pipeline. The inference is made that all such calculations when made will be based on a pipeline operating under certain assumed normal conditions. For example, it is stated,3/ "Frost heave in cold permafrost areas (ground temperature less than 30°F) is not anticipated to be a significant problem due to:

1. Shallow active layer,

2. Low ground temperature, and

3. Rapid freezeback of thawed soils beneath the pipeline."

1/Applicant's Submission, Exhibit G-I, p. 3.
2/Ibid., Exhibit Z2, Sect.3.2, 3.3.
3/Ibid., Sect.3.2, p. 4.

(ii) Analysis of Submission

Frost heave in permafrost areas may be a problem if the pipeline is not always operating at subfreezing temperatures. Specific sections also may be exposed to atmospheric temperatures much lower than ground temperatures. The Applicant implied this by stating that the line could be subjected to a low temperature of minus 60°F when the line is in operation.1/ In fact, several pipeline temperature modes may be possible as follows:

1. Preoperating period, including the period of construction.

2. Test period, comprising the use of relatively warm, high heat transfer test fluid.

3. Operating periods under conditions of approximately 25°F gas temperature.

4. Unusual operating periods when refrigeration is unavailable due to machinery or power failure and/or compressor coolers failing to function.

5. Stoppage of gas flow by closing a block valve and trapping of the high pressure gas in an above ground section at abnormally low temperatures.

The Applicant has not addressed quantitatively the range of temperature possibilities that may occur with a pipeline buried to a shallow depth (approximately three feet of overburden cover) in permafrost, which occurs in the northern reaches of the pipeline; and in discontinuous permafrost, which occurs in the more southerly areas which would be traversed by the proposed pipeline.

The Applicant did present a state-of-the-art model for use in making such calculations.2/

A principal geotechnic effect of freezing temperatures in non-permafrost soils is "frost heave." This soil movement is created by the expansion of the water as it is frozen into ice and by the water that migrates in front of the freeze front. Such earth movements will produce a strain on a pipeline traversing the soil such that a stress will be produced in the pipeline walls, its supports, if any, and associated connections. This stress is additive to the normal operating stresses. If sufficiently great (the severity can also be increased by repetition), the total stresses in the material may exceed the ultimate strength and rupture will occur.

1/Applicant's Submission, Exhibit Z2, Sect. 3.3, p. iii.
2/Ibid., Sect. 3.1.

The Applicant stated that in the discontinuous permafrost regions the pipeline could be designed to eliminate frost heave by using one or more of the following measures:1/

1. Increased burial depth

2. Surcharge loading

3. Soil replacement with more suitable soil

4. Lowering water table

5. Insulation of pipeline

Although it is highly probable that recourse to one or more of these expedients would be productive in eliminating undesirable environmental effects in certain circumstances, no discussion is given indicating how, when or where they would be used and what would be the quantitative effects of their application.

If a pipeline is to be constructed with a high level of confidence in its integrity, it must be capable of withstanding all loads that may be imposed upon it. The Applicant's Submission does not present the calculations for all of the temperature induced loads and consequently the stresses resulting therefrom, but indicates that such calculations will be made in due course as the design proceeds.

(iii) Conclusions

1. The Applicant's model for calculating earth temperatures is considered appropriate for application to the pipeline design. This technique could be used to arrive at a design knowledge of the effect of all temperature conditions on pipeline stresses and thus the integrity of the pipeline. The temperature conditions are numerous. They depend on weather, soil type, free water, flooding, thickness of the active layer, the nearness of the permafrost, and the several possible conditions of pipeline operation, design and installation such as lying dormant, hydrostatic testing, operation with no refrigeration or after-compression cooling, use of insulated pipe walls, and deviations from normal burial depth (both up and down) and no burial at all (exposed to atmospheric temperature fluctuations.)

2. The Submission lacks specific numerical data needed to calculate fully the effects of both earth and atmospheric temperatures on the pipeline throughout its length. It is not possible to fully evaluate the geotechnic integrity of the proposed pipeline until such quantitative temperature data become available.

1/Applicant's Submission, Exhibit Z2, Sect. 3.2, p. 4.

3. The validity of chilling the pipeline throughout the distance from Delta Junction has not been proven conclusively. Such proof would require considerable additional detailed review, including consideration of elevating the line over that part of the route unsuitable for a buried, uncooled line.

D. MEASURES TO ENHANCE THE ENVIRONMENT OR TO AVOID OR MITIGATE ADVERSE ENVIRONMENTAL EFFECTS

1. Pipeline

a. Design

iii. Engineering

(1) Facilities

(c) Operating Pressure and Temperature

(i) Applicant's Submission

The Applicant submitted in Exhibit Z2, Section 2, the formulae and data used to calculate the operating pressures and temperatures of the flowing gas. A gas composition stated to be representative of the Prudhoe Bay product was used to calculate typical physical properties which were then used in standard thermodynamic equations to calculate the power requirements to compress and cool the gas to the desired operating values. In Exhibit G of the Applicant's Submission, flow diagrams are presented as follows:

	Summer Average Day	Summer Peak Design	Winter Peak Design
1981	x		
1982	x		
1983	x	x	x

These flow diagrams also present pressure, temperatures and power requirements.

(ii) Analysis of Submission

The equations described by the Applicant were stated to have been used in a computer program developed by Foothills Pipe Lines, Ltd.[1/] to determine temperature, pressure and velocity conditions in the pipeline. The calculations thus made require gas property information which was obtained from a typical analysis of Prudhoe Bay gas. To determine what variations might be expected in the computed results, the Prudhoe gas composition given by Alcan[2/] was compared to

1/Applicant's Submission, Exhibit Z2, Sect. 2, p. 1.
2/Ibid., p. 16.

that presented in two other proposals. The comparisons are shown below:

Component	Alcan	Arctic[3]	El Paso[4]
	Mole %		
N_2	0.772	0.75	0.75
CO_2	1.000	1.00	1.02
C_1	86.440	85.11	85.91
C_2	7.390	7.70	7.77
C_3	3.430	3.99	3.93
iC_4	0.370	0.50	0.26
nC_4	0.492	0.73	0.30
iC_5	0.060	0.11	0.03
nC_5	0.041	0.09	0.02
C_6	0.005	0.02	0.01
H.V.[1]	1122	1145	----
S.G.[2]	0.6503	0.665	0.653
Mol. wt.	18.25	----	18.8

The friction between the pipe wall and the flowing gas and between the gas molecules (viscosity) are the factors creating the prime flow resistance. Of these factors, the wall friction factor is the chief reason for energy being expended in moving the gas through the pipe. To corroborate this, the "Reynolds Number"

1/H.V=higher heating value in BTU's per cubic foot of dry gas.
2/S.G.=specific gravity compared to air=1.
3/Alaskan Arctic Gas Application, Exhibit G-II, p. 31.
4/El Paso Application, Vol. I, Exhibit G, Fig. 1.

characteristic of the flow was calculated using the following equation:1/

$$Re = \frac{4R_h G}{\mu}$$

$$\text{where } R_h = \frac{\text{cross sectional area}}{\text{perimeter}} = \frac{\frac{\pi D^2}{4}}{\pi D} = \frac{D}{4}$$

Substituting: $$Re = \frac{DG}{\mu}$$

where Re = Reynolds Number
G = mean gas velocity in the pipe, feet/second
D = pipe inside diameter, feet
μ = kinematic velocity in feet^2 per second

Solving: $$Re = \frac{\frac{40.8}{12}(36.1)}{1.436 \times 10^{-6}}$$

$$= 85{,}000{,}000.$$

This high value indicates that the flow through the pipe is essentially turbulent in nature. Kays2/ indicates a dividing line between turbulent and laminar flow at a Reynolds Number of about 2000.

This calculation shows a Reynolds flow characteristic sufficiently high so that the gas flow in the pipe can be suitably predicted using the equations presented by the Applicant.

The Applicant stated3/ that an effective roughness index of 250 microinch was used in determining pressure drop and that this figure is based on an internally coated pipe. This value represents a high quality internal coating. Such a coating is not mentioned in the pipe specification.4/ Internal coatings are described by the American Petroleum Institute5/ and could be referred to by the Applicant.

The maximum design pressure used by the Applicant of 1250 psig6/ is relatively conservative. This pressure allows the use of thinner wall pipe than that needed by other Applicants employing higher gas pressures. This consideration does not include external (environmental) factors that create increased loadings on the

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1/Kays, W. M., Corrective Heat and Mass Transfer, 1966, p. 58.
2/Ibid., p. 59.
3/Applicant's Submission, Exhibit Z2, Sect. 2, p. 16.
4/Ibid., Sect. 3.4.
5/American Petroleum Institute, "Recommended Practice for Internal Coating of Line Pipe for Gas Transmission Service," API RP5L2, February 1968.
6/Applicant's Submission, Exhibit G-I, p. 3.

pipe, which are discussed elsewhere.

The pressure drop between compressor stations determines the load on the compressors and hence the horsepower required to drive the compressors. This determination was made in a standard manner with certain acceptable assumptions of:

1. Negligible change in kinetic energy between suction and discharge,

2. Negligible error due to use of average values for gas compressibility and temperature change exponents.

The actual compressor discharge temperature was calculated using an average exponent which is considered acceptable, but the value of the exponent used was not given. Inasmuch as a statement was made[1] that the effect of heat flux through the compressor wall can be ignored, it was considered that the effect of this assumption on compressor horsepower should be examined. The horsepower requirements are presented in Exhibits G, G-I, and G-II. In the absence of specific calculations made by the Applicant, which could be checked for validity, a comparison was made between the horsepower requirements of the Applicant's proposed summer peak design throughput of 2567 MMSCFD and the horsepower values submitted by El Paso Alaska Company. The following table shows the comparison between Alcan and El Paso:

	Alcan Pipeline Co.	El Paso Alaska Co.
Distance, miles	731.4	809.2
Gas flow, MMSCFD (maximum value)	2,567.0	3,490.0
Required compression horsepower	337,539.0	494,339.0
Horsepower hours required per day = (24)(Hp.)	8,100,936.0	11,864,136.0
Hp.-hrs. required per million cu. ft. gas per mile $= \frac{\text{Hp.-hrs.}}{\text{MMSCFD x miles}}$	4.315	4.201

This comparison shows a remarkably good correlation between two separate sources. As indicated above, the equations are fairly standardized, the chief variable being the efficiency of the compressor which is generally assumed to be 80%. Due to advances in compressor design, the latest generation of compressors is performing with somewhat higher efficiencies.

1/Applicant's Submission, Exhibit Z2, Sect. 2, p. 14.

Because of the composition of natural gas, it deviates in its characteristics from a "perfect" or "ideal" gas and consequently displays certain properties not predictable from the "ideal" gas laws. One of these, called the "Joule-Thomson Effect," comprises the change in the temperature of the gas resulting from a change in pressure with no change in heat content. The practical effect of this gas property is for the gas to cool during its passage from one compressor station to the next, the degree of cooling being dependent upon the reduction of pressure between stations and the heat transfer between the surrounding soil and the pipe. This latter effect is zero when the soil and pipe are at the same temperature. With a temperature difference, the heat will flow in the direction of the lower temperature. The rate of this heat flow is partially dependent on the magnitude of the temperature difference. It is also dependent on the nature of the fill around the pipe and the adjacent soil. Inasmuch as radical differences in soil composition and consequently heat transfer characteristics exist along the proposed pipeline route, calculated predictions of heat transfer rates are only valid if based on proper knowledge of the specific soil and its characteristics at the specific place in question. However, in spite of these variations, it is necessary to make predictions in order to ascertain the power requirements of the chillers. The Applicant has presented equations for these calculations which are suitable for use if appropriate data on conditions controlling heat transfer are used. For a first estimate, the Applicant considered a number of conditions to be constant. These included:

1. Ground surface temperature,

2. Ground thermal conductivity,

3. Coefficient for the gas film inside the pipe wall.

In addition, it is stated[1]/ that the ground temperature was assumed to be uniform and that the latent heat effect of ground moisture content was ignored in the calculations. The two statements concerning:

1. Constancy of surface temperature and

2. Uniformity of ground temperature

appear to be interrelated, and consequently their collective meaning is not clear. No results of heat transfer calculations are presented, but such results were doubtless obtained as they are needed for estimating the required horsepower to drive the chillers. Obviously, in the final design, it will be necessary to accurately determine the heat transfer to and from the surrounding soil for each increment of the route which displays a change in the nature of the soil. Such calculations must be made for the various seasonal conditions and the several potential operating conditions including an expected lengthy period of nonoperation

1/Applicant's Submission, Exhibit Z2, Sect. 2, p. 13.

after the pipe has been laid. This is necessary for computing accurately the chiller power requirements and also in order to form an intelligent opinion of prospective changes in the environment including melting and icing conditions and their effects on pipe integrity.

The Applicant did not present any consideration of gas surge and the attendant overpressure due to rapid valve closing operation unless controls are designed to prevent it. A surge would be most likely to occur during an emergency shutdown. The phenomenon results from a sudden reduction in gas velocity to zero which creates a rise in pressure which travels through the gaseous medium at the speed of sound. The rise in pressure is calculated by means of the following formula:1/

$$\Delta P = \text{Mass Flow (m) x velocity of pressure wave relative to undisturbed gas (C)}$$

$$\Delta P = mC$$

$$C = \sqrt{\left(\frac{P_1}{P_2}\right)(RTZg)}$$

$$\frac{P_1}{P_2} = \frac{\text{discharge pressure}}{\text{suction pressure}}$$

$$R = \text{Gas Constant} = \frac{1546}{\text{mol. wt.}} = \frac{1546}{18.75} = 82.5$$

$$T = \text{Temperature of gas (average)}$$

$$Z = \text{Compressibility Factor}$$

$$g = \text{gravity}$$

Substituting: $$C = \sqrt{\left(\frac{1265}{1003}\right)(82.5)(474)(0.645)(32.2)}$$

$$= \sqrt{1024324} = 1012 \text{ ft./sec.}$$

$$\Delta P = (14.7)\left(\frac{2567 \times 10^6}{60 \times 60 \times 24}\right)\left(\frac{1}{32.2}\right)\left(\frac{1}{82.5}\right)\left(\frac{1}{520}\right)\left(\frac{1}{9.62}\right)(1012)$$

$$= 33.2 \text{ lb./in.}^2$$

The velocity of the pressure wave with respect to the flowing gas is approximately 1000 feet/second. The average flowing gas velocity is 36 feet/second.

1/U.S. DOI, Final Geotechnic Evaluation, Alaska Pipeline, Report No. ATR-76(7551)-1 Rev. 1, January 1976.

If it became necessary to close a valve suddenly in an emergency, a pressure wave would be created which would travel away from the valve at approximately a 1000 feet/second velocity until a reflection occurred, probably by another stop valve. To prevent the full rise in pressure, the valve should close in a time in seconds greater than 2(L/1000) where L is the distance in feet from the valve to the reflector. For example, if valves were spaced every 15 miles, the closing time should exceed (2)(5280)(15)/1000 or 158 seconds.

The amount of over pressure of 33 psi to be tolerated would require an additional thickness of pipe wall as follows:

$$t = \frac{1337 + 33.2}{1337}(0.600) - 0.600$$

$$= 0.015 \text{ inch (rounded)}$$

The value of 0.600 is the wall thickness in inches specified by the Applicant. The determination of this value is discussed in Section D.1.a.iii.(2)(a), Pipe Wall Thickness. The value of 1337 is the maximum allowable internal pressure in pounds per square inch based on a code requirement1/ that the hoop stress shall not exceed 0.72 x the specific minimum yield strength of 65,000 pounds per square inch.

The power required for chilling the gas at each of the several compressor stations was presented by the Applicant in Exhibits G-I and G-II. The methods used to make the calculations are presented in Exhibit Z2, Section 2, pp. 21-26. The actual calculations used to produce the stated power requirements are not presented. To evaluate the validity of these calculations, a comparison was made of the refrigeration horsepower requirements computed by Alcan and by El Paso Alaska Co. They are presented below.

Comparison of Refrigeration
Power Requirements

	Alcan Pipeline Co.	El Paso Alaska Co.
Distance, miles	731.4	809.2
Gas Flow, MMSCFD (maximum value)	2,567	3,490
Required chiller horsepower	123,446	85,043
Chiller horsepower per mile per million cu. ft.	0.06575	0.03011
Average gas temperature °F	15	15

1/Code of Federal Regulations, Title 49, Sect. 192.101-111, p. 833.

This comparison indicates a liberal estimate by Alcan of the compression power required. There should be no problem in attaining the desired gas chilling effect.

(iii) Conclusions

1. The Applicant has displayed an adequate knowledge of gas pipeline system design from the standpoint of presenting equations suitable for use in calculating the many design data required. A considerable gap exists, however, between these equations and the pressures, temperatures, power requirements, gas velocities, heat flux and other descriptors of the proposed system. This gap is comprised of the many actual calculations that need to be made. If they, or samples of them, had been included in the Submission, a more specific, complete and helpful critique of the Applicant's proposal could have been produced.

2. The Applicant did not include an analysis of the effect of pressure surge due to rapid valve closing. This surge, if not prevented, would require an increase in pipe wall thickness of 0.015 inch.

D. MEASURES TO ENHANCE THE ENVIRONMENT OR TO AVOID OR MITIGATE ADVERSE ENVIRONMENTAL EFFECTS

1. Pipeline Systems

a. Design

iii. Engineering

(1) Facilities

(d) Air Quality Change

(i) Applicant's Submission

The Applicant stated that during the construction phase, equipment exhaust emissions would be high locally and the chief air contamination would be the dust resulting from construction activity; that compressor stations would produce negligible quantities of carbon monoxide, nitrogen oxides and sulfur compounds. In the winter, the chief problem might be ice fogs in the immediate vicinity of the compressor stations and other pollutant concentrations would not be serious. No information was given on the amounts of pollutants that would be generated.

The data[1]/ provided by the Applicant are summarized in Table 2, Ambient Air Quality Standards for the State of Alaska and the Federal Government. Additional controls have been established by the State of Alaska for industrial and similar processes[2]/ as follows:

> The State of Alaska has air quality regulations, governing open burning, incinerators, and industrial process or fuel burning equipment, all of which may be applied to this proposed pipeline project. Pertinent examples of these special regulations are: no open burning except by permit and no open burning during "Air Quality Advisory" days, i.e. days of heavy pollution or adverse weather which are announced by radio or television. Industrial and Fuel Burning Processes may not exceed 0.05 grains/cubic foot of particulate matter emitted; not more than 500 ppm measured as SO_2, but occurring as any sulfur compound may be emitted. If Carbon Monoxide levels in any one locale exceed 10 mg/m^3, all motor vehicle traffic (except emergency vehicles) shall be routed out of that locale. The Alaskan Air Pollution Control Regulations (Chapter 50, amended November 9, 1972, authority AS46.03.1501 and others) may

1/Applicant's Submission, Exhibit Z-1, Vol. 1, Sect. 2, pp. 2-302 to 2-304.
2/*Ibid.*, p. 2-305.

TABLE 2 -- AMBIENT AIR QUALITY STANDARDS OF THE STATE OF ALASKA AND THE FEDERAL GOVERNMENT

Pollutant	Primary1/	Secondary2/
Particulates,		
Annual geometric mean	75 μg/m^3 (75) 3/	60 μg/m^3 (60)
Maximum 24-hour concentration4/	260 μg/m^3 (260)	150 μg/m^3 (150)
Sulfur Oxides (as SO_2)		
Annual arithmetic mean	60 μg/m^3 (80)	
Maximum 24-hour concentration4/	260 μg/m^3 (365)	
Maximum 3-hour concentration4/	1300 μg/m^3 (1300)	
Carbon Monoxide5/		
Maximum 8-hour concentration4/	10 mg/m^3 (10)	
Maximum one-hour concentration4/	40 mg/m^3 (40)	
Photo Oxidants		
Maximum one-hour concentration	160 μg/m^3 (160)	
Hydrocarbons		
Maximum 3-hour concentration (6-9 A.M.)	160 μg/m^3 (160)	
Nitrogen Oxides		
Annual arithmetic mean	100 μg/m^3 (100)	

1/Primary, set for protection of public health.
2/Secondary, set for protection of public welfare.
3/Figures in parentheses denote National Air Quality Values.
4/Not to be exceeded more than once per year.
5/Carbon Monoxide emissions have special limitation. See quotes p. 81-82.

require any industrial process which generates pollutant and/or water vapor to obtain a special permit and to reduce water emissions, if that process will occur in areas of potential ice fog.

The Applicant further stated as follows:1/

The Construction impacts on air quality generally will be temporary in nature, and will vary depending on the season and the time of day. The approximate period for construction activities is May through September, with the possible (and probable) addition of March-April and October-November, depending on weather conditions at the time. During the season, dust will undoubtedly be the primary particulate matter added to the air environment. Historically, air quality measurements have been made only at Fairbanks. Air quality statistics there show that serious problems do exist, from dust in summer and from construction by-products in winter. Construction camps on the haul road cannot be considered similar to Fairbanks but, given a particular set of conditions, it is possible that critical concentrations can be reached in the camps and along the road. Because surface winds are stronger during the warmest part of the day, (also the least likely time for a temperature inversion), dust particle concentrations would tend to be greatest during the light wind, inversion-prone night hours.

Construction activities prior to March and after November will probably be conducted with a snow cover, usually hard packed on the roads. Dust will then be eliminated, except where traffic removes the snow, and even then the ground will be frozen and much less likely to produce dust. Combustion products, assuming comparable amounts of vehicular activity, should develop higher concentrations than during summer months. Surface winds are much lighter, and temperature inversions stronger and occur more frequently.

Construction camps or activity centers are potential producers of air pollutants. During the construction period of March through November combustion by-products may briefly build minor local concentrations, but should pose no serious problem. If extensive construction work were done during winter months, temperature inversion and "no wind"

1/Applicant's Submission, Exhibit Z-1, Vol. 1, Sect. 3, p. 3-9.

conditions for an extended period could cause pollutants to reach critical concentrations in the immediate vicinity of the pollutant source.

(ii) Analysis of Submission

It has been reported[1] that the exhaust products from 30,000 horsepower gas turbine powered compressor/ chiller stations would be as follows:

Exhaust gas, cu. ft./sec.	5315
cu. ft./hr.	1.91×10^7
Water vapor, %	3.9
Carbon dioxide, %	2.1
Nitrogen, %	77.5
Oxygen, %	16.5

The Applicant has reported that under maximum flow conditions of 2567 MSCFD, attained by the summer of 1983, that the maximum power would be used at compressor station No. 8. This power is calculated as follows:

Compressor, hp.	23,376
Refrigeration, hp.	9,598
Station power, hp.	1,600[2]
Total, hp.	34,574
Total hp. rounded	34,600

The Applicant has indicated that a modified aircraft type gas turbine gas producer with an industrial type power turbine would be used for the compressor prime mover. More conventional industrial gas turbines would be used to drive the electric generators. With this information, a gross estimate may be made of the exhaust gas quantity and the percent of exhaust gas constituents.

1/U.S. DoI, Final Geotechnic Evaluation, Alaskan Pipeline, Report No. ATR-76(7551)-1 Rev. 1, January 1976, p. 167.
2/This value is based on two of the three generator sets running at 2/3 of their maximum capacity.

Using the maximum power developed at compressor station No. 8, the following assumed values were used in performing calculations.

Specific air rate, lb./hp.-hr = 35

Overall thermal efficiency, % = 25

The exhaust gas weight is calculated as follows:

Total air rate, lbs. air per hr. = hp. x specific air rate
= (34,600)(35) = 1,211,000

Heat input, BTU/hr. $= \frac{(34,600)}{0.25} \times 2545 = 3.52 \times 10^8$

Fuel gas requirement, cu. ft./hr. $= \frac{\text{heat input}}{\text{lower heating value in BTU/cu.ft.}}$
$= \frac{3.52 \times 10^8}{960} = 3.67 \times 10^5$

Fuel gas rate, lb./hr. = cu. ft./hr. x gas density
$(3.67 \times 10^5)(0.0526) = 1.93 \times 10^4$

Heat release rate, BTU/lb. of air $= \frac{\text{heat input}}{\text{air rate}} = \frac{3.52 \times 10^8}{1,211,000} = 2.91 \times 10^2$

Exhaust heat (enthalpy), BTU/lb. = (1 - efficiency)(heat release rate)
= 0.75(291) = 218

Exhaust temperature, °F1/ = 918

Exhaust Weight, lb./hr. (rounded) = Air rate + Fuel gas rate
= 1,211,000 + 19,300
= 1,230,300

If the fuel contains no more than 10 grains of total sulfur per 100 cubic feet, which is the limit established in the transportation tariff furnished with the Application, this would result in an emission of $\frac{10}{100} \times 3.67 \times 10^5$ which equals 3.67×10^4 grains of sulfur per hour at the compressor station. Expressed as sulfur dioxide, it would be $\frac{64}{32} \times 3.64 \times 10^4$ which equals 7.28×10^4 grains per hour. This is equal to $7.28 \times 10^4(0.000143)$ or 10.4 pounds of sulfur dioxide per hour where 0.000143 is the conversion factor for grains to pounds. The exhaust gas weight was stated above to be 1,230,300 pounds per hour. Therefore, the percentage of sulfur dioxide in the exhaust would be $\frac{10.4 \times 100}{1,230,300}$ which equals

1/From John W. Sawyer, Editor, Gas Turbine Engineering Handbook, Vol. II, 1972, p. 26.

0.000845% or 8.45 parts per million. This quantity of sulfur dioxide is much less than is produced by gas turbines burning liquid fuels. Such fuels contain from 0.1% to 1.0% by weight of total sulfur. Consequently, liquid fuel burning engines would produce total sulfur in the range of 4 to 40 times the amount calculated above for the turbines burning the pipeline gas.

Gas turbines produce only traces of carbon monoxide except under conditions of extremely high loads, during idle conditions, and during start-up when slightly greater amounts of carbon monoxide may be produced.

The amount of nitrogen oxides produced is primarily dependent on the combustor gas temperature. These oxides increase with temperature. Consequently, a high specific output combustor will produce more oxides of nitrogen than one of low specific output. However, because all gas turbines operate with large quantities of surplus air which tend to hold combustor temperatures to a low value, nitrogen oxide emissions are not considered serious as they are much less than are produced by higher combustion temperature gasoline engines.

Modern gas turbines, especially derivatives of the aircraft type, burn fuel with high combustion efficiency. This means that only negligible amounts of unburned or partially burned fuel products are produced. Visual inspection of the exhaust for smoke is a good test for the absence of such materials. As the amount of incomplete products of combustion increases, the exhaust becomes more dense (blacker). The exhaust should be clear, except for condensed water vapor, in a properly maintained turbine.

The exhaust sulfur dioxide concentration, calculated above, of 8.45 parts per million will dissipate rapidly such that only much smaller concentrations will reach ground level. Because of the high temperature of the exhaust gas, 900°F or greater, the density is such that the gas will tend to rise quite rapidly. Tall exhaust stacks will also aid in effecting rapid dissipation of the exhaust products.

(iii) Conclusions

1. The maximum generated horsepower at any one compressor station is about 34,600. The chief noxious atmospheric contaminants are sulfur oxides (chiefly SO_2), a mixture of nitrogen compounds and incomplete products of combustion of the fuel.

2. The sulfur is limited in the fuel to 10 grains per 100 cubic feet of gas which results in a quantity of sulfur compounds in the exhaust that is considered acceptable.

3. In normal operation of the gas turbine power plant, carbon monoxide is not considered a hazard.

4. Nitrogen oxides would be present in the exhaust. The amount depends on the load on the turbine and its design. Relatively speaking, the problem is of much less magnitude than with gasoline engines.

5. Hydrocarbons in the exhaust and their incomplete combustion products are factors resulting from turbine design and maintenance. Attention to turbine operation such that the exhaust gases are colorless is a good control.

D. MEASURE TO ENHANCE THE ENVIRONMENT OR TO AVOID OR MITIGATE ADVERSE ENVIRONMENTAL EFFECTS

1. Pipeline system

a. Design

iii. Engineering

(1) Facilities

(e) Gas Treatment

(i) Applicant's Submission

The pipeline system would not provide for any processing or treatment of the flowing gas except for inlet gas and fuel gas scrubbers at each compression station. The initial gas product accepted at Prudhoe Bay for transportation through the pipeline would correspond with the following specifications taken from the Applicant's Submission:1/

1. Shall not contain dust, gums, solid matter, or gum forming substances which may be injurious to pipelines;

2. Oxygen content shall not exceed one percent by volume;

3. Shall not contain liquid water or hydrocarbons in liquid form. Shall be free of hydrocarbons liquefiable at temperatures in excess of 15°F at 800 psia.

4. Shall not contain more than 1/4 grain of hydrogen sulfide per 100 cubic feet;

5. Shall not contain more than 10 grains of total sulfur per 100 cubic feet; and

6. Shall not contain more than two percent by volume of carbon dioxide.

After the gas enters the pipeline, it would only be subjected to pressure and temperature changes resulting from frictional losses and heat transfer with the pipe wall.

(ii) Analysis of Submission

The Prudhoe Bay raw gas contains relatively high concentrations of carbon dioxide and sulfur, which would be substantially reduced at the initial processing/compression station before

1/Applicant's Submission, Exhibit Z-7, pp. 306-7.

delivery to the pipeline.[1] This initial processing station would not be part of the pipeline system. The Applicant has not discussed the consequences of improper processing by the Supplier of the gas including the potential for formation of liquids and solids. The way has been left open for this to occur in that the Applicant's Submission[2] states that the Company (Alcan Pipeline Company) can accept gas not conforming to the specification and make changes necessary to bring it into conformance. The Applicant has considered the consequences of fueling the compressor and chilling equipment with pipeline gas, and would use a fuel gas scrubber to render the gas suitable for use in the gas turbine prime movers.

The control on hydrocarbons condensing out of the gas in a liquid state is the Applicant's statement that none shall be liquefiable at temperatures above 15°F at 800 psia. However, the actual temperatures encountered by the cold gas may be considerably less than 15°F during operation. The Applicant's Exhibit G-I, page 4, shows a gas temperature down to 4°F at a gas pressure of 999 psig. This latter temperature is the temperature leaving the chiller. Assuming a temperature differential from chilled surface to gas sufficient to create a necessary heat flux, the gas immediately in contact with the chiller surface will probably exist at a temperature near 0°F or lower.

The amount of water in the gas is of significance in connection with pipeline integrity. If it condenses out to form ice in a finely divided form, the ice would erode surfaces which it might contact at high velocity. It also might deposit and freeze on surfaces of instruments or controls such as safety valves and thermostats causing possible malfunctions. Ice deposits on compressor impellers and flow passages would produce inefficient performance and mechanical unbalance, tending to cause vibration with increased probability of mechanical failures. Ice formed on chiller surfaces would reduce their capacity resulting in either excessive power drains or hot gas or both.

To maintain the system ice-free requires that water not condense out of the gas under any operating condition.

(iii) Conclusions

1. No processing or treatment (other than scrubbing and chilling) of the gas along the pipeline should be necessary if the composition of the input gas mixture meets the Applicant's specifications.

1/U.S. DoI, Final Geotechnic Evaluation, Alaskan Pipeline, Report No. ATR-76(7551)-1, Rev. 1, January 1976, p. 85.
2/Applicant's Submission, Exhibit Z-7, pp. 307-8.

2. The formation of liquid or solid phases would directly affect the external environment only during blow down or in the event of a large leak developing.

3. The specified values to prevent hydrocarbon and water condensates from forming in the gas line are unsuitable for the purpose intended in that the temperatures of 15°F and 0°F respectively are too high and the pressure of 800 psia for hydrocarbons is too low.

4. If the Applicant intends to accept off-specification gas from the Supplier, gas purification equipment will be required as part of the total system to bring it into compliance with specification requirements.

D. MEASURES TO ENHANCE THE ENVIRONMENT OR TO AVOID OR MITIGATE ADVERSE ENVIRONMENTAL EFFECTS

1. Pipeline System

a. Design

iii. Engineering

(1) Facilities

(f) Valves, Controls, and Pipeline

(i) Applicant's Submission

The operations and maintenance plan of the Applicant is based on the use of automatic, unattended equipment at the measurement and maintenance stations, communication sites, and mainline block valves. A communication system extending along the entire length of the pipeline would provide voice services, data transmission for the supervisory control systems, and maintenance and operating information related to equipment performance. The proposed communications and pipeline control system is discussed in Section D.1.a.ii.

Main line block valves would be located at the two main line metering stations, at each compressor station and at intermediate distances between compressor stations. The distances between valves are summarized below:

Average distance between valves, mile					-- 15.9
Minimum	"	"	"	"	-- 13.9
Maximum	"	"	"	"	-- 20.2

The Applicant did not provide a detailed description of the main line block valves nor of their installation. The Submission does state that all large station valves would be ball-type with ends and trim to suit the design service.[1] Valve operators would be air piloted, gas-hydraulic powered and electrically activated. Other than this, there is no mention of how block valves would be controlled, what signals they would respond to, how they would function, nor whether their condition (open or closed) would be a part of the Master Control Center display. Blow down valves are also not described.

1/Applicant's Submission, Exhibit Z2, Sect. 4, p. 7.

The pipeline is described as consisting of 42-inch outside diameter pipe with a wall thickness of 0.600 inch except in locations where it crosses roads where the wall thickness would be increased to 0.675 inch. The pipe would be cleaned, prime coated and taped just before it is lowered into the pipe trench. Pipe lengths as delivered to the trench site are stated to be 80 feet in length.

(ii) Analysis of Submission

The location of block valves along the gas pipeline is adequate and well within the federal requirements of 20 miles maximum spacing1/ for Class 1 locations, except for the spacing between valve No. 3 and compressor station No. 2, which are located at Mile Posts 63.5 and 83.7 respectively.2/ This is a separation distance of 20.2 miles, or 0.2 mile over the code requirement. The Applicant did not discuss blow down operations; pressure relief valves; safety shutdown in the event of excessive gas pressure buildup; nature of the internal pipe surface; increases in pipe wall thickness at meter and compressor stations and pipeline and river crossings; block valve installations; test methods for block valves; methods of handling pipe to avoid strength-reducing damage; pipeline cleaning methods as a part of maintenance and operation; the effect of heat conduction from above ground piping to buried pipe and thence to the permafrost; methods of detecting and locating leaks; foundation design for valve systems; protection of vent openings; or composition and heat treatment of the specific material from which the pipe would be manufactured. The description of the valves, and pipeline hardware given by the Applicant is a general description only. The pipe thickness could also be increased wherever the pipe crosses the work pad, because it would be subjected to heavy loading by construction and maintenance equipment at those relatively unprotected locations.

(iii) Conclusions

1. The Applicant's Submission includes a general overview of the pipeline and its auxiliary hardware. A number of items are described, but many important elements are omitted as discussed above. These omissions prevent a satisfactory understanding of the total control concept.

2. The spacing between block valve No. 3 and compressor station No. 2 of 20.2 miles is not in compliance with the code requirement that no point in the line shall be more than 10 miles from a block valve.

1/Code of Federal Regulations, Title 49, Section 192.179, p. 839.
2/Applicant's Submission, Exhibit Z2, Sect. 1, Drawing No. APC-B9-3 and 4.

iv. From a safety standpoint, improved pipeline integrity would result from an increase of pipe wall thickness where the pipe crosses under all roads, including haul roads, work pads, other pipelines, over or under streams, and at compressor stations, meter stations and block valves.

D. MEASURES TO ENHANCE THE ENVIRONMENT OR TO AVOID OR MITIGATE ADVERSE ENVIRONMENTAL EFFECTS

1. Pipeline System

a. Design

iii. Engineering

(1) Facilities

(g) Thermal Interaction Between a Chilled Gas Pipeline and a Hot Oil Pipeline

(i) Applicant's Submission

The Applicant has investigated analytically the heat flow characteristics of a system involving the Alyeska hot oil pipeline and the proposed chilled natural gas pipeline.1/ This was necessary because the oil line is buried for approximately 50% of its route, and the proposed gas pipeline would run adjacent to the buried portion of the oil pipeline over several hundred miles of the route.

For purposes of comparative analysis, the conceptualized oil line is 48 inches in diameter, has 3 feet of cover (when buried), and the average oil temperature is 150°F. The gas line assumed for the comparison is 42 inches in diameter, has 4 feet of cover,2/ and the average gas temperature is 15°F. Only the buried condition of the oil pipeline was considered. A representative stratigraphy of soil was chosen typical of the vicinity of Fairbanks, Alaska. Average conditions assumed were as follows:

Ground temperature, °F	30-31	
Active layer depth, ft.	6	
Soil Composition	Silt and fine sand	
	Silt	Fine sand
Water content, % of dry wt.	30	22
Total density, #/cu. ft.	110	122
Thermal conductivity, BTU/hr./ft./°F		
Frozen	1.08	0.23
Unfrozen	0.37	0.33
Latent Heat, BTU/cu. ft.	3600	3170

1/Applicant Exhibit Z2, Sect. 3.1, p. 7-14.
2/The normal cover is intended to be about three feet.

Meteorological data for Fairbanks included:

	Minimum Value 12 months	Maximum Value 12 months
Ambient Temp., °F (Mean temp. for 15th day of month)	- 10.0	+ 61.0
Wind Velocity, Mph (Mean velocity for 15th day of month)	3.00	6.80
Snow Depth, Ft. (Mean depth for 15th day of month)	0.00	1.38
Average Solar Radiation, BTU/hr./Sq. ft. (Mean value for 15th day of month)	0.920	78.7

It was assumed that the two pipelines would be separated by a distance of 78 feet, one on each side of a gravel pad. The ground surface factors considered and their values are shown below:

Properties of Snow:

Thermal Conductivity	0.20 BTU/hr./ft./°F
Surface Emissivity	0.95
Surface Absorptivity	0.40

Properties of ground:

Surface Emissivity	0.90
Surface Absorptivity	0.80

Evapotranspiration Factor:

Natural Surface	0.25
Gravel Surface	0.10

Greenhouse Factor: 0.837

Convection Correlation Coefficient: 0.02

These data were used in the computation of a geothermal model by EBA Engineering Consultants, Ltd. with a team led by C. T. Hwang, a well-known authority on the subject.

The results were calculated for a period of operation of ten years. They show a progressive depression (increase in depth) of the 32°F isotherm directly below the hot oil pipe during the 10 years from 20 feet depth after year 1 to 50 feet depth after year 10. At the chilled gas pipe, the results show a downward movement of the 32°F isotherm from a depth of about three feet after year 1 to a depth of about five feet at the end of year 10. Without the gas pipeline, the 32°F isotherm remains the same (as indicated above) under and near the hot line.

The Applicant's Submission also shows results of calculations for heat transfer in the immediate vicinity of the hot oil line. After ten years of operation without the gas pipeline, a value of 19.606 BTU/hr./sq. ft. was calculated. With the gas pipeline, a value of 19.610 BTU/hr./sq. ft. was found. The difference is 0.004 BTU/hr./sq. ft.

No analysis was made of the situation involving the crossing of the two pipelines where both would be buried.

(ii) Analysis of Submission

The input data used by the Applicant to make the calculations have been reviewed. They are considered suitable for the use made of them. The assumptions made appear reasonable for the purpose intended. The geothermal model as described is a treatment in considerable depth of many extremely complex phenomena. An opportunity did not exist to examine the various programs such as SETTLE and HEAT used in the computations; however, the statement is made by the engineer in charge, C. T. Hwang, P. E., that "the geothermal model has been verified by field performance at various test facilities and related projects, with satisfactory results."1/

The temperature of the gas pipeline from station to station was stated to vary from a high value of 25°F to a low value of 4°F. Change in hot pipe temperature would occur from point to point also. Climate changes will occur from year to year and from season to season.

If the hot oil line is considered alone, some heat flow to the earth would result merely because of the temperature differences between the line and the earth. The effect of adding the chilled line in the vicinity of the existing hot oil line would be to increase the heat flow away from the hot line and in the direction of the colder line. Consequently, the placement of the chilled line in the vicinity of the hot line would tend to reduce the rate of melting of the permafrost between the two lines. The results presented by the Applicant shows this effect would occur after year 10 at about 35 feet laterally in the direction of the cold line and 25 feet vertically below the hot line.2/

1/Applicant's Submission, Exhibit Z2, Sect. 3.1, p. 14.
2/Ibid., Drawing No. 3 facing p. 9.

The effect on the chilled line would be two-fold. One effect would be to cause more heat to be transferred from the surrounding warmer earth to the cold pipeline. The second effect would be a tendency to create a region of ice-free earth surrounding the chilled line, which would otherwise be frozen. This latter tendency is due to the fact that the Applicant's model shows that the temperature gradient between the hot line and the surrounding earth temperature would be greater than the temperature gradient between the chilled line and the earth. The calculation submitted by the Applicant shows a gradually diminishing movement of the 32°F isotherm laterally outward from the hot line with time up to ten years (the limit of the calculation). After ten years, the chilled line continued to exist in a frozen zone (less than 32°F). As this isotherm movement would eventually reach zero, the effect might never cause the permafrost immediately under the chilled line to melt. This is the more probable case, under the conditions given, because the chiller load at the compressor station would doubtless be increased to maintain the desired low gas temperature.

The model presented by the Applicant represents only one set of conditions among many. Probably the extreme scenario would be one wherein the gas pipe would be laid in frozen ground during the colder months of the year, so that the heat from the hot pipe would combine with the next summer's heat to create a thaw zone below the gas pipe. Such circumstances might produce a sag bend. The chances of this happening are not high, however, as the hot pipe is normally elevated in the ice-rich permafrost area, plus the fact that the heat from a buried hot pipe is not shown to effectively penetrate the 78 feet distance to the chilled pipe location for at least two years.

A buried pipe crossing of the hot oil line and the chilled gas line would probably involve the chilled line running underneath the hot line. However, due to the considerable depth of burial of the hot line in some areas, the opposite case is also possible. The crossings of the Alcan gas line with the Alyeska oil line are shown in the strip maps1/ to occur at some locations where the oil line is above ground and at other locations with the oil line buried. In at least one instance (at the Atigun River) a crossover of the two lines is shown to occur below the riverbed. The crossovers noted are listed in Table 3.

1/Applicant's Submission, Exhibits Z2 and Z6.

TABLE 3 - CROSSOVERS OF PROPOSED ALCAN GAS PIPELINE WITH ALYESKA OIL PIPELINE

(Taken from Strip maps contained in Exhibit Z2 and 1"=1000' strip maps, Exhibit Z6, APC-D9-"X")

Milepost	Oil Line Situation
90.5	Above ground
105.0	" "
127.0	" "
144.7	" "
145.5	" "
146.5	" "
155.1	Buried
160.8	"
170	"
171	"
252.2	Above ground
275.5	" "
310.4	Buried
312.3	"
378	Above ground
379	" "
386.8	" "
529.5	Buried
539	"

A large number of possibilities for crossovers exist. They include:

1. Elevated cold line -- buried hot line
2. Elevated hot line -- buried chilled line
3. Both lines elevated
4. Both lines buried, chilled line uppermost
5. Both lines buried, hot line uppermost.

In addition to the geometrical variations, a number of ground conditions could exist at crossovers. They include:

1. Permafrost -- winter -- ice rich
2. Permafrost -- winter -- ice poor
3. Permafrost -- summer -- crossover in active layer
4. Permafrost -- summer -- crossover below active layer
5. Permafrost -- summer -- crossover at active layer interface
6. Nonpermafrost -- summer
7. Nonpermafrost -- winter -- crossover in frost layer
8. Nonpermafrost -- winter -- crossover at frost layer interface
9. Nonpermafrost -- winter -- crossover below frost layer.

Many of these possibilities need little discussion because of lack of thermal interaction between the pipes or because the designer would not allow the situations to exist. For example:

1. The situations involving one or both lines elevated above ground would result in no significant thermal interaction.
2. Burial of the hot line in ice rich permafrost is not contemplated by Alyeska.
3. Because the 32°F isotherm may extend outward from the buried hot oil line for up to 50' (summer conditions)1/ after 10 years of operation, the hot oil line would provide a nonpermafrost type environment for any of the chilled line crossings that have been noted.

1/Applicant's Submission, Exhibit Z2, Sect. 3.1, Drawing No. 3.

(iii) Conclusions

1. It is concluded that the presence of the chilled line at a distance of 78 feet laterally from the buried hot oil pipeline is a negligible factor in the operation and maintenance of the hot oil line.

2. It is also concluded that the presence of the chilled line can only have a beneficial effect on the relationship of the hot oil line to its environment in that the effect would be a tendency for the permafrost to be less affected (melted) by the hot line.

3. The magnitude of the effect of the hot line on the integrity of the chilled pipeline is not determinable based on the data submitted. The information presented does indicate a tendency for this effect not to be an important factor in the operation of the chilled gas line in that the permafrost under the chilled line (at a distance of 78 feet from the hot line) might not be melted for many years, if ever, due to the hot line's presence. However, this effect should increase in magnitude possibly to the point of creating a problem, as the separation distance between the two lines is decreased.

4. Information on the interaction effects of one pipeline on the other at crossovers was not presented. It is concluded, however, that no significant thermal interaction would occur except with both lines buried and that this would principally affect the frost bulb formation around the chilled gas pipe. Whether the effect would be to reduce or increase the size of the frost bulb would require a series of calculations similar to the prototype calculations submitted by the Applicant in Exhibit Z2-3.1, pp. 7-14.

D. MEASURES TO ENHANCE THE ENVIRONMENT OR TO AVOID OR MITIGATE ADVERSE ENVIRONMENTAL EFFECTS

1. Pipeline System

a. Design

iii. Engineering

(2) Piping

(a) Wall Thickness

(i) Applicant's Submission

The Applicant has stated that the pipe would consist of 42-inch outside diameter, 0.600-inch wall thickness, API 5LX-65 or 5LS-65 pipe with metallurgy applicable to Arctic conditions.1/ The Applicant's Submission does not state how a wall thickness of 0.600 inch was determined to be the requirement. However, the stress analysis shown using the external loadings presented in the sample calculations together with a wall thickness of 0.600 inch gives a combined stress for the steel designated which is within the allowable limits. The pipeline would be constructed, operated, and maintained in accordance with the U.S. Department of Transportation, Hazardous Materials Regulations Board Requirements, Title 49, Chapter 1, Part 192 entitled "Transportation of Natural and Other Gas by Pipeline: Minimum Federal Safety Standards." The minimum strengths for this pipe are specified by the American Petroleum Institute2/ at 65,000 psi yield and 77,000 psi tensile. The API also lists3/ wall thicknesses for High-Test Line Pipe, Grade X65, ranging from 0.344 inch to 1.250 inch. The wall thickness of 0.600 inch proposed by the Applicant1/ is not listed in the API specifications. The nearest value shown by the API is 0.625 inch.

The Applicant's Submission contains a specification for Large Diameter High-Test Line Pipe prepared by Gulf Interstate Engineering Company4/ which requires that the pipe shall meet the minimum requirements of API Specifications 5LX5/ or 5LS6/, latest edition, and shall also meet any additional requirements as set forth therein or on the accompanying Request for Quotation or Purchase Order. Neither of these specifications describe a metallurgy suitable

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1/Applicant's Submission, Exhibit G-II, p. 1.
2/American Petroleum Institute, "API Specification for High-Test Line Pipe," API Spec. 5LX, 20th ed., March 1975.
3/Ibid., p. 21.
4/Applicant's Submission, Exhibit Z2, Sect. 3.4, p. 1.
5/American Petroleum Institute, "API Specifications for High-Test Line Pipe," API Spec. 5LX, 20th ed., March 1975, p. 8.
6/American Petroleum Institute, "API Specification for Spiral-Weld Pipe," API Spec. 5LS, 8th ed., March 1975.

for Arctic conditions although the Applicant implied that such metallurgy was contained therein by making the statement:[1] "Detailed data for the pipeline material specifications are found in Exhibit Z-2."

The Applicant provided in Section 3.3 of Exhibit Z2, a Pipe Stress Analysis which describes the design methods and procedures the Applicant proposed to use to ensure structural integrity of the pipeline during construction and operation. This Pipe Stress Analysis was prepared for Energy Systems Engineering Ltd. of Calgary, Alberta, Canada, by Pipe Line Technologists Ltd., Calgary.

The Pipe Stress Analysis method presented by the Applicant was used to make limited scope investigations of a number of design considerations for soil conditions and to establish typical pipe loadings resulting from these soil conditions. In addition, the pipe loading resulting from an earthquake of 8.5 Richter magnitude was calculated. The preliminary calculations did not show significant design limitations over the range of conditions considered. The Applicant stated an intent to investigate the entire range of possible conditions along the proposed pipeline route prior to final design[2] and after winning the necessary approvals to proceed.

The Applicant's Submission indicates a design approach as follows:

1. Establish the geotechnical initiated loadings to which the pipe will be subjected.

2. Establish the loadings resulting from the contemplated functions of the line.

3. Establish limits for critical aspects of pipeline behavior which should not be exceeded.

4. Perform parametric studies to establish pipeline geometry, which will withstand the imposed loads without exceeding the limits established in (3) above.

5. Repeat calculations as necessary based on a mile-by-mile evaluation of the route.

The Applicant also identified fifteen types of load sources which need to be evaluated and the resulting stresses determined. They are

1. Internal pressure (hoop and axial stress)

2. Temperature differences

1/Applicant's Submission, Exhibit G-II, p. 1.
2/*Ibid*., Exhibit Z2, Sect. 3.3, p. ii.

3. Bends: side, over and sag types

4. Pipe anchors and earth restraints

5. Ice wedge cracking

6. Ice-rich soils

7. Seismic waves

8. Faults

9. Overburden

10. Construction practices

11. Water crossings

12. Frost heave

13. Buoyancy

14. Differential settlement

15. Unstabilized support

Each of the above sources of pipeline loading are addressed in the Applicant's Proposal. Certain sample calculations were made and the results presented as examples of the many design calculations the Applicant would expect to make in the event a permit were granted.

(ii) Analysis of Submission

The Applicant's Submission included many sources of pipe stresses including those resulting from geotechnic factors. The preliminary studies described in Exhibit Z2, Section 6.4 of the Submission corroborate this. As the Applicant has indicated, the results presented are preliminary in nature. If and when the investigation of imposed loads is continued by the Applicant, it would be necessary to review such factors as the selection of the pipe material, the stress-relieving procedures chosen and pipe wall thickness calculations to determine what effect, if any, such later determined loads will have on the initial decisions concerning these factors.

No mention was made of the effect of valve closing on pressure surge in the pipeline. This subject was discussed previously and an analysis was presented in Section D.1.a.iii.(1)(c). The result of that analysis indicates a small increase in pipeline loading and stress level equivalent to 33 psi in internal gas pressure. This potential overpressure would probably require recalculation when the design has proceeded to a point where an exact knowledge of valve closure rates and the internal geometry of each section of the pipeline have been developed.

The functionally induced loads on the pipe can be quite accurately determined. This process proceeds through a series of approximations, which become more accurate as decisions are made concerning operating conditions and the various aspects of the design are finalized. A first approximation of the geotechnically induced loads can be made by using an analytical model incorporating the best knowledge of each pertinent natural condition and its interaction with the prospective pipeline. Successive iterations of the determinations of these interaction effects would allow an improvement in the accuracy of the estimate. However, all such determinations are limited by the understanding of the natural conditions involved and the quantitative effects of such conditions. The next major step in improving accuracy of such predictions is to develop an experimental model and subject it to test under the conditions which the proposed pipeline would be subjected to. A test somewhat similar to this has been described[1/][2/] in previous reports. For ease in understanding the results, one such test summary is quoted below:[1/]

> The data presented for the Prudhoe Bay test section show axial forces, vertical and horizontal bending moments, and vertical displacements of each 800-foot long test leg for a period covering approximately 15 months. The reported results indicate very low pipe stresses as well as small pipe displacements. However, only small credence may be put in the vertical deflection measurements as presented by the Applicant since they were made with transit rather than a level, were conducted by inexperienced surveyors, were not obtained as part of a conventional, closed loop, level circuit and are admittedly not self-consistent.
>
> The strain gage data show that stresses in the test loop were generally low during the 15-month period; but, since, the gages were not installed and/or calibrated until after the pipe was in the ditch, the installation stresses were not measured. A check of the cross section constants used in data reduction indicates that the data were for a 0.28 inch wall thickness pipe rather than the 0.9 inch wall pipe scheduled for use. No discussion of the correlation between the two pipe sizes is given.

1/U.S. DoI, Final Geotechnic Evaluation, Alaskan Pipeline, Report No. ATR 76 (7557)-1, Rev. 1, January 1976, pp. 9-10.

2/Environmental Report of Alaskan Arctic Gas Pipeline Co., Section D, pp. 35-36.

The above quoted test summary indicates the necessity of obtaining more knowledge of actual geotechnic effects in order to improve the accuracy of predictions derived from an analytical model. Soil, ground water and permafrost conditions and their mechanical and temperature interactions with the Alyeska oil pipeline should be helpful. Some detailed soil information already exists on the Alyeska oil pipeline route and that of the Alaska Highway from Delta Junction to the Yukon Border. Less well known are the interactions between the soil types and the buried, refrigerated pipeline. Such unknowns result in uncorroborated analytical predictions.

(iii) Conclusions

1. The Applicant's Submission indicates a considerable familiarity with the geotechnic sources of loading on the pipeline as well as the functionally imposed loads. It is concluded that it was on the basis of this familiarity that a pipe wall thickness of 0.600 inch was chosen as satisfactory for withstanding all such loads under the conditions assumed in the calculations.

2. No calculations are shown which would determine the magnitude of stresses at potential stress-raising defects which would tend to increase the probability of pipe rupture at subzero temperatures. As an example, the calculation for the effect of an earthquake does not consider:

a. That the pipe may be quite cold at the time of the quakes,

b. Whether stress-raising flaws exist in the metal,

c. Whether gas is or is not flowing (to maintain pipe temperature),

d. Whether the pipe is buried or exposed to the atmosphere,

e. Whether the material is brittle or ductile

3. The need for a more sophisticated stress analysis incorporating consideration of concentrated stress in the material is indicated because of the tremendous energy stored in a highly pressurized gas pipeline which is potentially more powerful than a large bomb.

4. The calculations did not show the effect of pressure surges due to rapid closing of stop valves. As approximate calculations of this pressure indicates it to be about 33 psi and to require an additional thickness of steel of 0.015 inch in the pipe wall.

5. The various crossings, comprising water, road and pipeline, are not described in detail in the Submission nor are the stresses resulting therefrom determined. Certain

factors which could add to the total load on the pipe were not mentioned in the Submission. They include:

a. Temperature differentials which would be increased at above-ground, exposed sections,

b. Long-time integrity which may be jeopardized by corrosive effects on above-ground portions of the pipeline as well as on buried sections,

c. Anchors and hardpoints produced by supports which may result in higher stress levels,

d. Seismic activity which also might produce higher stress levels at elevated portions of the pipeline because the supports tend to act as long moment arms.

D. <u>MEASURES TO ENHANCE THE ENVIRONMENT OR TO AVOID OR MITIGATE ADVERSE ENVIRONMENTAL EFFECTS</u>

1. Pipeline System

a. Design

iii. Engineering

(2) Piping

(b) Corrosion Prevention

(i) Applicant's Submission

Pipeline corrosion control would be based on the use of both coating and cathodic protection systems. External coating and tape wrapping were stated to be applied during construction. Above ground steel structures would be painted. Water systems would contain rust inhibitors. The projected technique for pipe wrapping would be to apply a continuous line travel tape coating over-the-ditch. Detectors would be used to check the integrity of the coating.

(ii) Analysis of Submission

The external coating system mentioned refers to a system which is more or less standard for unchilled lines. Its application to a chilled line requires assurance that the cement used will adhere strongly under low temperatures and that the integrity of the wrap will be complete. If holidays (minute openings) exist in the wrap, water will eventually creep by means of capillary action between the cement and steel pipe with consequent development of corrosion pockets in the pipe.

No description of the surface cleaning method to be used prior to coating is given. Adequate cleaning is a crucial step in the corrosion-prevention treatment.

The requirements for external corrosion protection are prescribed by Federal Government.1/ This requirement is not mentioned in the submission. If the Applicant coats the inside of the pipe for prevention of corrosion, then confirmation of the performance of the coating at low temperatures, down to at least minus 60°F is necessary to establish confidence in the material and procedures.

No description is given of the cathodic system, or when and how it would be installed and tested.

1/Code of Federal Regulations, Title 49, Part 192, Subpart 1.

(iii) Conclusion

Insufficient descriptions were provided in the Applicant's Submission to understand clearly how, when, and with what the pipeline system would be protected against corrosion, both internally and externally.

D. <u>MEASURES TO ENHANCE THE ENVIRONMENT OR TO AVOID OR MITIGATE ADVERSE ENVIRONMENTAL EFFECTS</u>

1. Pipeline System

a. Design

iii. Engineering

(2) Piping

(c) Corrosion Control Monitoring

(i) Applicant's Submission

The Applicant stated that cathodic protection monitoring will be performed by Alcan personnel on a regularly scheduled basis.1/

(ii) Analysis of Submission

Other than the above, the Applicant did not specifically describe a corrosion control monitoring plan in his Environmental Report. Monitoring includes the determination of the continuing effectiveness of the various corrosion prevention systems to be used and the location and amount of any corrosion that has occurred. This includes inspection prior to start-up to insure the integrity of the systems that have been applied. It means inspection of both internal and external coatings to insure that they have been properly repaired after welding operations, that electrical circuits for cathodic protection have continuity, that applied potentials are correct, that power sources are functioning and that instrumentation is providing accurate data.

(iii) Conclusion

The Applicant's Submission contains insufficient information on what is intended for corrosion systems monitoring.

1/Applicant's Submission, Vol. , Sect. 1, p. 1-41.

D. MEASURES TO ENHANCE THE ENVIRONMENT OR TO AVOID OR MITIGATE ADVERSE ENVIRONMENTAL EFFECTS

1. Pipeline System

a. Design

iii. Engineering

(2) Piping

(d) Welding

(i) Applicant's Submission

The Applicant has stated1/ that in order to establish preliminary welding procedures the Gulf Interstate Engineering Company (GIE) has been in contact with Lincoln Electric Company and has furnished to them the chemistry of the pipe to be used and GIE's recommendations as to welding procedures. Definitive welding procedures would not be established until pipe samples have been obtained and welded under these procedures. However, tests on similar pipe were stated to have indicated that the proposed welding procedure is in fact effective and produces welds of acceptable quality under governmental rules and regulations.

It is intended that for the double-jointed section pipe that Lincoln's 790 Flux and L-70 wire, or equal, would be utilized without preheat. Line pipe welds would be made using Lincoln 65+ rod or equal, with preheat up to 200-300^{o}F. Hot pass welders and stripper welders would follow stringer beads, depositing sufficient weld metal so that overnight temperature effects would not be detrimental to the welds. Three beads would be deposited in sequence before the conclusion of the day's work. Back-end welders would then complete the weld and the quality of their work would be confirmed by X-ray inspection and the interpretation thereof.

The Applicant also has stated2/ that at small stream crossings, the pipe may be laid by "walking the pipe into the trench from the work pad . . . " and that "As each section is taken to the water's edge, the next section is welded onto its end and the procedure repeated until the crossing pipe emerges at the opposite bank."

(ii) Analysis of Submission

Until the Applicant determines the final composition of the pipe steel, little valid information can be developed on the thickness of the pipe or methods of welding it.

1/Applicant's Submission, Exhibit Z2, Sect. 3.5, p. 1.
2/*Ibid.*, Sect. 6, p. 27.

Nowhere in the Submission has suitable information been given on the precise composition of the pipe steel. Steel composition for X65 Grade Pipe is given by the API. 1/ This composition is modified in the Submission 2/ and two types of steels are referred to, i.e., "pearlite reduced" and "accicular ferrite" types. It is not clear which one, if either, the Applicant proposed to use. This is confirmed by the statement in the Submission as follows 3/ "Final selection of welding procedures will be made after the results of welding tests on pipe of the specified metallurgy."

The necessity for preheat, an important part of the welding procedure, cannot be determined until the steel has been selected. However, the Submission states 4/ that the welding of double-jointed pipe would be done without preheat and that line pipe would be welded with preheat. The Submission is non-specific regarding the need for preheating of line pipe in that a statement is made:2/ "Pipe ends will be cleaned and preheated as required."

The cooling rate of a weldment also may require control depending on the type of steel being welded. The Submission states 5/ that the welder will deposit "sufficient and adequate weld material so that overnight temperature effects will not be detrimental to the welds." However, it is implied by the Submission5/ that the pipe may be welded and later immersed in water as part of a stream crossing procedure. Such a procedure might thus possibly produce a quench more drastic than cooling in air. Because of the non-specificity and tenuousness of the Applicant's statements above, the assistance of a consulting welding engineer, Mr. Jack Baker of Omaha, Nebraska, was obtained to analyze that part of the Submission relating to welding. A large number of detailed technical questions were posed by Mr. Baker which are pertinent to the discussion of welding. The letter submitted by Mr. Baker and the questions are contained in Appendix C of this Report. These technical welding questions encompass the following subjects:

Welding Procedures:

1. Base metal to be welded
2. Welding processes
3. Joint design
4. Electrode type and size

1/American Petroleum Institute, "API Specification 5LX for High-Test Line Pipe," API Spec. 5LX 20th ed., March 1975.
2/Applicant's Submission, Exhibit Z2, Sect. 3.4, p. 2.
3/*Ibid*., Sect. 6, p. 25, paragraph f.
4/*Ibid*., Sect. 3.5, p. 1.
5/*Ibid*., Sect. 6, p.27.

5. Voltage and amperage

6. Procedure for depositing weld metal

7. Alignment techniques

8. Base metal heating and cooling requirements

9. Ambient conditions before, during and after weld metal deposition

10. Methods for measuring and controlling welding operation

11. Hand welding

12. Machine welding

Testing of Welds:

1. Development and proof tests to corroborate validity of welding process

2. Sample tests as part of quality control

3. Non-destructive tests

4. Conditions for testing including subzero(°F) temperatures

5. Limiting values for acceptance of welds

Inspection and Quality Control (See Figure 12):

1. Quality control over prewelding conditions

2. Quality control during metal deposition process

3. Quality control during cooling period

4. Allowable reject rate

5. Corrective actions (repair welding)

6. Records to be made

7. Preservation of records

Personnel:

1. Qualifying and requalifying procedures

2. Training procedures

3. Disqualifying procedures

Figure 12 – Welding Repair Operations

The problems Alyeska has had with welding quality control and testing have been highly publicized. The lack of accurate testing data has required that some welds be retested and repaired as necessary. This photograph illustrates the scope of the effort required to excavate, retest, and repair those welds and amply demonstrates the environmental importance and economy of "doing it right the first time."

(iii) Conclusions

1. The Submission does not adequately describe the composition of the pipe steel which in turn prevents an adequate determination of welding requirements.

2. Welding procedures are not included in the Submission in sufficient detail or scope to allow their proper evaluation.

3. The method described for crossing small streams may prevent the desired controlled cooling of weldments.

D. MEASURES TO ENHANCE THE ENVIRONMENT OR TO AVOID OR MITIGATE ADVERSE ENVIRONMENTAL EFFECTS

1. Pipeline System

a. Design

iii. Engineering

(2) Piping

(e) Metallurgy

(i) Applicant's Submission

The Applicant has indicated that the pipe would be composed of steel complying with the requirements of the American Petroleum Institute specification 5LX for High-Test Line Pipe and a specification of the Gulf Interstate Engineering Company for Large Diameter High-Test Line Pipe.1/ Also stated is that the metallurgy of the pipe shall be applicable to Arctic conditions.2/ Both the API specification and the Gulf Interstate specification give pipe steel chemical composition and required heat treatment, but neither of the two specifications state that the materials specified shall be suitable for subzero temperatures (down to -60°F) nor do they imply it. Neither do they describe tests to be made on steels at temperatures below zero°F, although the Applicant has stated that the pipe steels will be subjected to operating temperatures ranging from plus 60°F to temperatures down to minus 60°F.3/

(ii) Analysis of Submission

Because of the lack of information supplied in the Submission on the composition and heat treatment of the specified Arctic type pipe material which has been proven by a background of testing and field experience to be adequate at the minimum contingency temperatures contemplated in chilled gas line Arctic service, the services of an engineering specialist in this field of technology were engaged to review the Submission. The consultant was Dr. Charles M. Gilmore, 9725 Schreiner Lane, Great Falls, Virginia 22066, a Professor of Mechanical Engineering at the George Washington University, Washington, D.C. Dr. Gilmore's study of the pipe material description made in the Applicant's Submission is attached to this report as Appendix D.

In brief, Dr. Gilmore indicates that steels of the type specified by the API and Gulf Interstate Engineering Company, unless modified in a manner not described in the Submission,

1/Applicant's Submission, Exhibit Z2, Sect. 3, p. 4.
2/*Ibid.*, Exhibit G-II, p. 1.
3/*Ibid.*, Exhibit Z2, Sect. 3.3, p. iii.

pass through a transition from a ductile condition to a brittle condition when they are cooled down. This transition occurs as the temperature is reduced from above the freezing point of water to about $0^{o}F$. At $0^{o}F$, the steel may already be in a mildly brittle zone. At minus $60^{o}F$, it would probably be highly brittle. The extreme brittleness renders the steel highly sensitive to fracture initiation, especially if a stress concentration created by a flaw such as a critical size of notch or crack exists. Such imperfection can easily be created during manufacture, by rough handling, by corrosion or by welding. The usual hydrostatic testing made at above freezing temperatures is unsatisfactory in revealing such defects. Only tests made at the low temperatures associated with service are satisfactory in proving the material to be acceptable from the brittleness standpoint.

Failure of pressurized chilled gas pipelines can occur as a result of defects formed in the pipe wall, which finally penetrate through the wall allowing the gas to leak through the opening. If the material is ductile, such a split or crack may gradually increase until detection occurs and a repair is made.

On the other hand, if the pipe steel is brittle, a failure would not occur gradually as indicated above, but could occur catastrophically, creating a long seam-like rip in the pipe or even rupturing the pipe in such a manner that a large section of the steel pipe wall would be blown away, thus liberating, more or less instantaneously, the enormous energy of the high pressure gas to create major damage to the surroundings.

Increasing the thickness of the chilled pipe does little to prevent these brittle failures as it is not the average stress throughout the pipe wall that causes failure. It is the high, concentrated stress at the root of a notch, crack or other flaw incurred by a dynamic load which initiates the rupture. This, in turn, is sustained by the internal pressure to become a run-a-way propagating type of rip or tear in the metal.

To prevent the conditions which lead to a propagating rupture, it is necessary to maximize the fracture initiation toughness of the pipe. To accomplish this, it may be necessary to conduct more research into fracture initiation phenomena of pipe materials if an acceptable low cost steel is obtained.

A cut, dent, weld crevice, corrosion pocket, or other relatively large indentation or crack can raise local stresses to values which tend to initiate brittle fracture. Care in manufacture and subsequent handling of the pipe is essential. Careful inspection in the field will identify handling-incurred flaws which denote unsuitable pipe. In addition, samples of pipe material and of weldments obtained frequently and subjected to suitable low temperature tests will provide information for assessing the dynamic toughness of the pipe.

In order to learn what extreme minimums in atmospheric temperatures might be encountered along the proposed pipeline route, a search was made of the National Oceanic and Atmospheric Administration (NOAA) archives for the 12-year period of 1962-1973. The prevalence of temperatures in the range of minus 60°F and below was noted for various weather stations along the proposed route. Starting at the Yukon Border terminus and moving toward Prudhoe Bay, the weather stations studied were: Northway FAA AP, Tok, Big Delta WSD AP, Fairbanks WSD AP, Prospect Creek Camp and Coldfoot Camp. It was found that atmospheric temperature fell below minus 60°F at one or more locations along the route for all 12 years except in 1964. In 1972, the temperature fell to minus 60°F or below for eleven days at Prospect Creek Camp, reaching a record low for the year of minus 70°F. It also fell below minus 60°F for four days at Coldfoot Camp. It was noted that extreme low temperatures were measured in the area where the pipeline would cross the Arctic Circle and also at the S.E. end where it would cross the Border into Yukon Territory.

(iii) Conclusions

1. Pipe material with the composition specified in the Submission is unsuitable for Arctic chilled pipeline service. If used, this steel would have a high probability of catastrophic rupture (brittle fracture) of the pipe when very low pipe temperatures (below zero°F) are encountered.

2. Suitable tests exist for use in choosing and specifying proper materials for chilled pipeline use. Among these are the Drop Weight Tear Test and the Charpy V-Notch Test. The tests, to yield significant results, must be made at temperatures corresponding to the lowest temperature the material is likely to meet in service.

3. In Alaska the lowest temperature encountered may be below minus 60°F, which would be encountered occasionally along the Pipeline route.

4. There is some probability of the pipeline steel attaining a temperature of minus 60°F while fully pressurized if the gas flow is stopped due to a block valve closure, and the pipe is not buried so that it would be fully exposed to the existing ambient air temperature.

D. <u>MEASURES TO ENHANCE THE ENVIRONMENT OR TO AVOID OR MITIGATE ADVERSE ENVIRONMENTAL EFFECTS</u>

1. Pipeline System

a. Design

iii. Engineering

(3) Testing Procedures

(a) Hydrostatic Testing

(i) Applicant's Submission

The Applicant has proposed to hydrostatically test the pipeline after back filling and in accordance with the Code of Federal Regulations, Part 192, Title 49.

Field line piping would be tested at 1.1 times the maximum allowable operating pressure, which would not cause a stress in excess of 0.72 times the specified minimum yield strength.1/ Piping in compressor and meter stations, road crossings, to and from block valves and river crossings would be tested at 1.5 times the design maximum allowable operating pressure.

Water would be used as the pressure test fluid and treated to comply with environmental standards before returning it to the natural drainage.

The pipeline would be tested in segments, the lengths of which would be dependent in part upon the pipeline route elevation changes. Test segments would be chosen so that the minimum required test pressure is developed at the highest elevation on that test segment while the pressure concurrently developed at the lowest point in the test segment would not cause an internal tangential stress of more than 95 percent of the yield strength of the pipe material. Each segment would be tested to the above minimum pressure specification for a minimum of 24 hours. Pressures would be verified by dead weight gauges and a continuous record of pressures and temperatures would be obtained by recording instruments.

(ii) Analysis of Submission

The Applicant would use water for hydrostatic testing of the pipe, but did not indicate the source of the water. At compressor stations, the Applicant's Submission 2/ indicated that fresh water would be obtained from local wells or trucked to the site from

1/Specified in American Petroleum Institute, "API Specification for High-Test Line Pipe," API Spec. 5LX 20th ed., March 1975, as 65,000 psi for Grade X65 pipe.

2/Applicant's Submission, Exhibit Z2, Sect. 4, pp. 7-8.

available sources. The amount of water required is dependent on the length of pipe to be tested. The nominal volume per mile is

$$(3.5)^2(0.785)(7.48)(5280) = 380{,}000 \text{ gallons}$$

A surplus for contingencies of about 10% would increase the volume to about 420,000 gallons per mile that would need to be obtained, stored and transported.

It appears that the hydrostatic test of 1.1 times maximum allowable operating pressure (which is a variable depending on pipe wall thickness) may be on the low side considering the pipe damage that might occur during the laying of the pipe, the low operating temperatures to which the pipe could be exposed, and the possibility of sporadic extremely low temperatures during the winter season if temperature control conceivably were lost for a period of time.

The application of the Code of Federal Regulations, Part 192, as the only control in the highly critical area of pressure testing is questionable considering that Part 192 was probably developed primarily for conditions quite different from those existing in a chilled gas pipeline operating in Alaska. Furthermore, considering that steels of the type generally used for pipe construction become increasingly notch sensitive as the temperature is decreased,[1] a higher test pressure is desirable merely to maintain a desirable level of confidence in the integrity of the pipe.

The American Petroleum Institute Specification 5LX of March 1975 specified that hydrostatic tests on high-test line pipe X65 Grade, 0.625-inch wall thickness, should be conducted at 1740 psi, which is 1.3 times the maximum allowable working pressure. This API test produces a stress in the material which is

$$S = \frac{PD}{2t} = \frac{(1740)(42)}{2(0.625)} = 58{,}460 \text{ psi}$$

where S = stress, psi

P = internal pressure, psi

D = outside diameter, inches

t = wall thickness, inches

This stress is equal to $\frac{58{,}460}{65{,}000}$ or 90% of the specified minimum yield stress (SMYS) of 65,000 psi which is sufficiently low so that the life of the material would not be degraded

1/Hayden, et al., The Structure and Properties of Materials, Vol. VIII 1965, p. 160.

as a result of the test. Care should also be taken to prevent the type accident illustrated in Figure 13, presumably due to overstressing during tests.

Applying the 90% factor to the Applicant's proposed pipe, the test pressure would be calculated as follows:

$$P = 0.9 \times \frac{2St}{D} = \frac{2(0.9)\quad(65,000)\quad(0.600)}{42} = 1671 \text{ psi}$$

which is $\frac{1671}{1337}$ or 125% of the maximum allowable working pressure.

The choice of a test fluid is difficult because there appears to be no ideal fluid. A gas used as a test fluid is dangerous in that tremendous energy would be stored in a test section filled with gas at high pressure. If the pipe ruptured, it would probably be in a catastrophic manner with the rapid venting of a large amount of stored energy which might wreak havoc with several hundred feet of pipe and trench. An advantage of gas is that it would leave the pipe fairly dry after the test. Probably the best gas to use, if gas is necessary, would be air. It will not freeze. It would be unnecessary to store it and a fresh supply would be always available. It is fireproof and less energy would be needed to chill it to a desirable low test temperature.

A liquid is inherently safer than a gas because it is relatively incompressible and contains less energy when compressed. Consequently, in the event of a pipe rupture, the pressure will be vented with release of much less energy than if a gas is used. The amount of liquid lost in a leak would equal the compressibility of the pipeful of liquid plus the volume expansion of the pipe under the imposed test pressure. This sum amounts to only a few hundred gallons for a mile length of pipe. Water is probably the cheapest and most plentiful liquid. It can be put back in the earth after its use. It is fireproof and easily handled. If a likelihood of freezing exists, water could be mixed with ethanol to depress the freezing point.

The fluid chosen should be one that lends itself to detection in the event of a leak, which also locates the pipe failure. An easily detectable odor might be used with either a gas or liquid. A fluorescent dye which can be activated by ultraviolet light might also be easily detected. The process would be similar to that used for flaw detection in non-destructive pipe inspections.

Some materials, especially water unless it is filtered, leave an undesirable residuum in the pipe. If air is chosen as the test fluid, a slight amount of moisture may condense on the walls. This can be eliminated by blowing dry air through the pipe or by treating with a desiccant such as ethyl or methyl alcohol. If water is used as the test fluid, considerable amounts of water would remain in the pipe after normal draining. The methods to be used to eliminate the last vestiges of liquid have not been described in the Submission, but air blowing or an alcohol rinse would aid in drying the pipe.

Figure 13 - Alyeska Pipeline Rupture

This 7-foot rupture occurred July 9, 1976, 10 miles east of Valdez during hydrostatic testing of one section of the Alyeska pipeline. Not only did the pipe rupture, in several places the 48-inch pipe was reportedly stretched to at least 50 inches. The loose material on either side of the rupture is the wrapping applied to the pipe to protect against corrosion. According to Alyeska, the rupture was caused by a pressure 31% greater than the design test pressure.

If the inside surfaces of pipe and fittings are suitably coated with an approved Epoxy resin, the opportunity for corrosion occurring during hydrostatic testing is greatly reduced. However, the coating must remain intact, without gaps, holes, and cracks which means that rough handling in the field must be guarded against. This is especially true during the operation of mechanical bending when internal fixtures are used to preserve pipe circularity. All areas subjected to the heat from welding operations and the weldments themselves must be cleaned and freshly coated with resin after completion of the welding to inhibit the corrosion of the otherwise exposed steel surfaces.

(iii) Conclusions

1. The Applicant's proposed hydrostatic test pressure of 1.1 times the maximum allowable working pressure of 1337 psi is considered too low to provide sufficient confidence in the integrity of the pipe. The confidence level can be increased significantly by using higher test pressures, which develop an internal hoop stress in all fabricated parts to approximately the same level as that to which the pipe was submitted in the test at the mill. For field pipe having a wall thickness of 0.600 inch, this test pressure would be 1.25 times the maximum allowable working pressure. For the thicker walled pipe used in more critical locations, the test pressure must be proportionally increased with wall thickness to attain the same confidence level.

2. A liquid is considered superior to a gas as a hydrostatic test fluid because of the greatly reduced hazard involved in the event of a pipe rupture.

3. Water is considered to be the superior material for a hydrostatic test liquid due to its lack of flammability, its safe handling characteristics, and the relative ease of disposal and resupply compared to other possible liquids. Care to prevent freezing, especially of the post draining water residues left in the pipe, would require special attention.

D. MEASURES TO ENHANCE THE ENVIRONMENT OR TO AVOID OR MITIGATE ADVERSE ENVIRONMENTAL EFFECTS

1. Pipeline System

a. Design

iii. Engineering

(3) Testing Procedures

(b) Water Quality

(i) Applicant's Submission

The Applicant has stated1/ that water will be used as the hydrotest fluid and that it will be disposed of by returning it to the environment after treatment and test to insure that it meets State and Federal environmental standards.

(ii) Analysis of Submission

The Applicant has not stated how leaks will be detected nor how the last vestiges of water will be removed from the pipe. Also the Submission does not state the quality of water to be used for hydrotesting.

If an additive of any sort is added to the water to aid in leak detection, it should be determined that the additive will not be harmful to the environment in the event a leak occurs.

Because of the harmful effect of residual water in the pipeline, it must be purged following the hydrostatic test. Methods to do this usually involve washing down the line with alcohol, either ethyl or methyl. From a safety standpoint, the less toxic, less volatile denatured ethyl alcohol is preferred. Its accidental release to the environment through minor spills or leakage of water mixed with ethyl alcohol should create no problem.

Tests are described2/ which indicate that high concentrations of material are not harmful to vegetation, that Arctic Char and Grayling were not adversely affected by 1% or less concentrations of methanol in water and that tests at Inuvik, Northwest Territory, have shown that water/methanol solutions do not affect forest tundra. However, such tundra may not be exactly like the vegetation on the Alaska North Slope. Also, the reaction of ethanol solutions may vary somewhat from the reaction with methanol solutions.

1/Applicant's Submission, Exhibit Z2, Sect. 3.6, p. 1.
2/U.S. DoI., Final Geotechnic Evaluation, Alaska Pipeline, Report No. ATR 76 (7557) - 1, Rev. 1, January 1976, p. 77.

(iii) Conclusions

1. Ethanol is considered a suitable material for use in purging water residues from the pipeline.

2. Although the tests referred to describe results with methanol, the similarity of the two substances, ethyl and methyl alcohol, is so great that mixtures of water and ethanol can be predicted (subject to confirmation) to have no greater effect on the environment than methanol-water solutions.

3. Ethanol can be salvaged for reuse using simple distillation equipment.

D. MEASURES TO ENHANCE THE ENVIRONMENT OR TO AVOID OR MITIGATE ADVERSE ENVIRONMENTAL EFFECTS

1. Pipeline System

a. Design

iii. Engineering

(3) Testing Procedures

(c) Testing and Start-up

(i) Applicant's Submission

The hydrotest procedure for the pipeline is described and evaluated in Section D.1.a.iii.(3)(a). The pipe would be x-rayed and coated as it joins the continuous string. The compressor station machinery would be tested at the manufacturer's plant prior to shipment.

A description of the start-up sequence has not been provided. In the Applicant's proposed construction schedule[1] for Compressor Station Construction, the items of "testing" and "start-up and commission" are listed. The scheduled events shown are as follows:

	1979	1980	1981	1982
Testing	Aug.-Sept.	Sept.-Nov.	July-Sept.	May & Aug.
Start up & Commission	Aug.-Sept.	Oct.-Dec.	Oct.	July-Sept.

It is also stated that construction of compressor stations would be timed to the gas flow build up.

The build up of the system is given as follows:

Year	Gas Flow MMSCFD Average	Stations With Compressors in Use	Stations With Chillers in Use	Meters in Use
1981	1200	2,6,10,14	4,5,7,8,9,11, 12,13,15	All 3
1982	1600	2,4,6,8,10,12, 14	All except 1 & 3	All 3
1983	2400	All 15	All 15	All 3

1/Applicant's Submission, Exhibit Z2, Sect. 6, p. 7.

(ii) Analysis of Submission

In general, the start-up procedures would be similar to those used in commissioning natural gas lines in the contiguous 48 states. However, there are unique conditions in Alaska that would require additional care in executing the pipeline start-up sequence.

If operation of the pipeline commences in the summer months, it would be necessary to control the start-up activity and associated traffic along the route to avoid damage to the terrain. Inasmuch as most start-up activity involves personnel rather than heavy equipment, much of the transportation would probably be via aircraft, with minimum impact on the environment.

Purging of the mainline could be accomplished using chilled gas. The Submission does not indicate if this will be done. Whether the slug of nitrogen gas, usually placed ahead of the purge pig, would require cooling would depend upon both its size and a thermal analysis. This analysis was not included in the Submission.

(iii) Conclusion

A complete analysis of start-up was not possible because a specific description of compressor station check-out and start-up procedures was not provided by the Applicant.

D. <u>MEASURE TO ENHANCE THE ENVIRONMENT OR TO AVOID OR MITIGATE ADVERSE ENVIRONMENTAL EFFECTS</u>

1. Pipeline System

a. Design

iii. Engineering

(4) Safety and Emergency Measures

(i) Applicant's Submission

Strict adherence of the Applicant to requirements and guidelines of DoT and other regulations, with inspection and enforcement by government agencies, would go far toward ensuring the safety of pipeline personnel during construction, operation, and maintenance of the Alcan Pipeline System. An important aspect of safety, particularly in the Arctic, is the availability of a reliable communications system for coordination, supervision, information exchange, reporting of accidents, and obtaining aid. The Applicant has proposed a dedicated system, i.e., a system with 48 communication channels assigned exclusively to this service which would provide the necessary communication services. A microwave system is proposed for long-distance transmission of voice, and a mobile radio system would be used for short-range communication between crews working and moving along the right-of-way. See Section D.1.a.ii. for evaluation of Applicant's proposed communications and control system.

Experience in any type of work is an important element in the assurance that satisfactory performance will result. The Applicant has proposed to follow the right-of-way of the Alyeska pipeline, the Haines pipeline, and the Alaska Highway. The experience gained by the builders of those routes would be used by the Applicant's construction teams wherever possible. The Applicant has stated that Alyeska experience and facilities would be utilized as follows:

1. Field data for design and construction, including detailed geotechnic and environmental information.

2. Temporary construction facilities such as construction camps, pipeyards, staging areas, borrow pits and construction equipment.

3. Permanent Alyeska facilities such as communication systems, haul roads, and work pads.

4. Procedures and methods including environmental restrictions, inspection techniques, knowledge of terrain, and deviations from normal practices required by the environment.

5. Work pads of the gravel type developed by Alyeska which will be used for the proposed summer construction period of March through November.

The Applicant has indicated that the proposed summer construction season eliminates certain variables and hazards associated with winter operations, such as working in the winter darkness, uncertainties of snow road construction and use, inclement weather such as "whiteouts," high winter winds on the North Slope, and extreme cold.

The Applicant would apply project management concepts, establishing procedures for design coordination, cost control, quality control, safety, and inspection.

(ii) Analysis of Submission

Little is said by the Applicant of the System Safety program other than a few general statements which would indicate an intent to conform to Federal and State Regulations. Training in safe working and construction procedures is fundamental. The Applicant's Submission does not describe such a program. Considering the remoteness of the work area and the frontier-like aspects of the environment, such a safety training program is needed continuously from the time a person is hired to the time of departure.

Fire prevention and fire fighting require training, equipment, procedures, and drills. Such a program is discussed herein in more detail under Section C.15, Analysis of Public Safety.

The fuel storage areas that will be required at each compressor station work camp, storage site and continuously along the route, as construction progresses, will include diesel fuel, pressurized gas, and gasoline. Other hazardous materials include hydrogen, acetylene, oxygen, and nitrogen. By allocating each of these materials its own space, hazards would be reduced. Excavations and berms to contain liquid fuel in the event of tank rupture will aid in isolating and reducing the hazard involved. Fire fighting materials located close to hazardous areas would also reduce potential damages from fire.

Acids and explosives are among the prospective hazardous materials to be handled. Personnel must be thoroughly trained in their safe use.

Waste materials consist of spoils and vegetation, camp wastes, and water. The camp wastes, primarily sewage and garbage, constitute a problem of disposal of considerable magnitude and difficulty. The Applicant has omitted discussion of how this material would be handled to insure health and environmental safety.

Aircraft, surface vehicles, and field personnel can be equipped with signal devices to assist in locating and recovery in the event they become lost. Other equipment may also need a permanent location indicator. Maintenance crews must be able to travel directly to damaged equipment, block valves, safety devices, control apparatus and communication aids during extreme cold, long nights, storms, and when the land is covered with several feet of snow. Homing devices might be useful for these extreme conditions.

A plan for caring for the sick and rendering aid to accident victims was not described. Personnel trained in first aid must be available close by during construction. Ready evacuation of injured or sick personnel by fixed wing or rotary wing aircraft as well as fast overland-vehicles must be planned for. Medical doctors would be required on call to consult with first aid personnel, to travel to sites of accidents, and to render professional assistance to those in need.

(iii) Conclusions

1. Applicant has not presented procedures for safe storage of flammable and other hazardous materials during construction, testing, operation, or maintenance of the pipeline.

2. The Applicant has not presented a System Safety Plan. Such a plan is necessary, not only to train personnel in doing their work safely, but to educate them regarding the hazards peculiar to their tasks and the pipeline project, and the reasons for the safety practices which must be adhered to in order to mitigate or avoid these hazards.

3. Signaling devices attached to air and surface vehicles, to personnel and to important parts of the pipeline such as block valves to allow their easy location in case of loss, inclement weather and at night would increase personnel and equipment safety and enhance maintenance and operational efficiency.

D. MEASURES TO ENHANCE THE ENVIRONMENT OR TO AVOID OR MITIGATE ADVERSE ENVIRONMENTAL EFFECTS

1. Pipeline System

b. Construction Measures

i. Civil Construction

(1) Work Pads

(a) Applicant's Submission

Details of planned construction techniques have been omitted by the Applicant. The Applicant has provided 1" = 1000' strip maps indicated the planned location of the gas pipe in relation to the Alyeska pipe, its relation to the work pad and its relation to existing cultural features. In addition to the 1" = 1000' strip maps, Exhibit Z2, Drawings APC-B9-1 through APC-B9-25 also indicate the pipeline route through Alaska on a scale of 1" = 2 miles. These drawings also show the gas pipeline in relation to Alyeska's pipeline, roads, and other cultural and natural features.

The Applicant has also presented proposed typical cross sections of the work pad and Alyeska and Alcan pipes, Drawings APC-S9-10 and 11. The same is also indicated in plan perspective in Exhibit Z2, Drawings APC-S9-12.

(b) Analysis of Submission

(i) Snow Pads

The use of snow pads has not been mentioned in the Application. This type of pad for winter or early spring construction normally produces little environmental impact, as is illustrated by Figure 14 which shows an elevated section of the Alyeska pipeline constructed with the use of a snow pad, (see also Figure 10, Section D.1.a.i.). It is, of course, necessary to have an adequate supply of snow available. The use of snow fences for accumulating snow in regions subject to considerable wind activity makes possible economic snow gathering in windy areas where snowfall is sparse. In areas where wind cannot be utilized to gather snow, late winter snow accumulations are usually deep enough to provide two feet of compacted snow which is generally sufficient for construction purposes. Snow pads have been used by Alyeska for a few miles in the North Slope foothills and on a hill north of Livengood. It appears that they can be utilized where a wind blown snow collection system can be established such as the North Slope. If the final pipeline alignment is designed to follow the Haines right-of-way in those permafrost, swampy regions from Midway Lake (Mile Post 667) to the Alaska-Yukon Border (Mile Post 731.4), then it is probable that winter snow pad construction would be advisable over some of those areas.

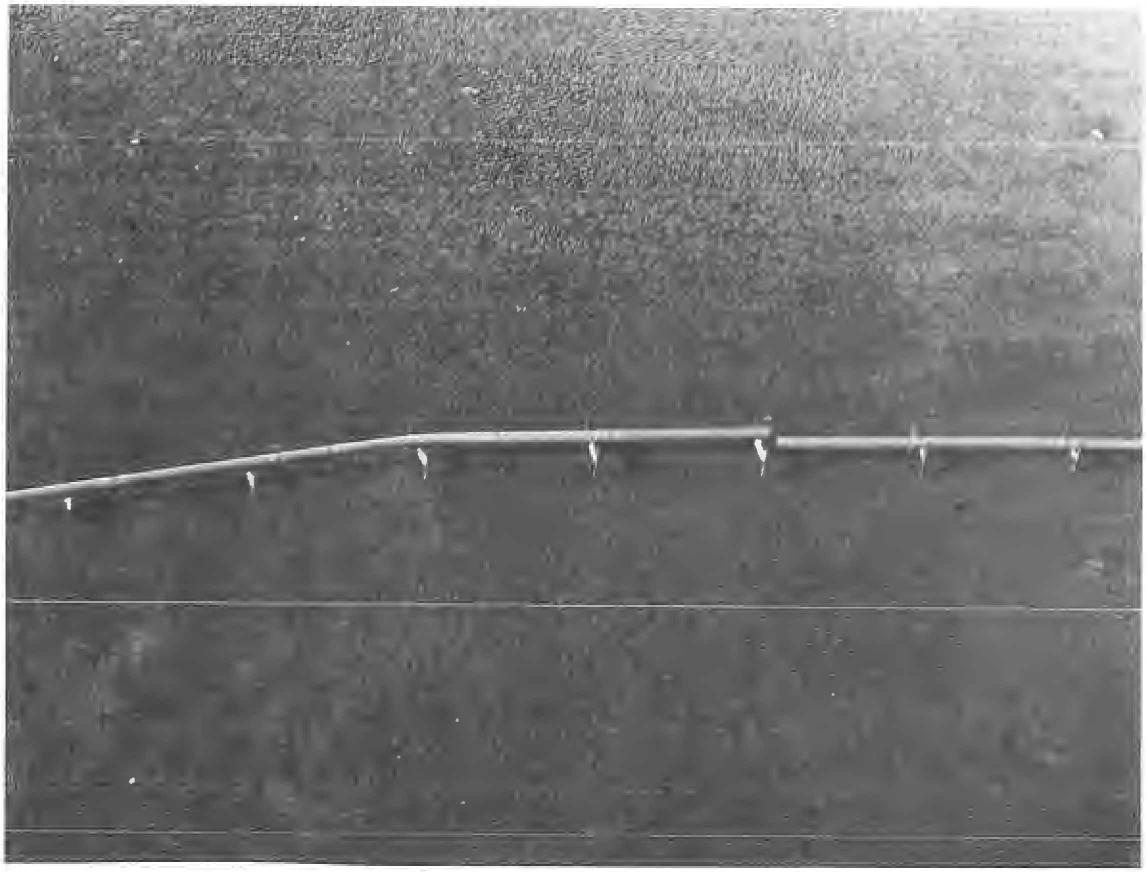

Figure 14 - Alyeska Pipeline Segment Constructed with Snow Work Pad

This photograph illustrates how well a snow work pad can protect the environment. It is difficult to determine on which side of the pipeline the work pad was situated. The photograph also demonstrates one of the disadvantages of snow pad construction, i.e., the pipe cannot be joined until the next winter after a new snow pad has been constructed. (Iroquois photo 8/25/76)

The possible use of snow pads in selected areas for late winter and early spring (pre-breakup) construction can be advantageous from two viewpoints:

1. Utilization of an annually renewable resource, thus eliminating the expense and environmental consequences of borrow pits and pit access roads as well as the expense of transporting and placing earth work pad materials.

2. Snow pads, obviously, self-destruct each summer. Thus, except for clearing of bushes and trees where necessary, the ground surface may be relatively undisturbed except

in the immediate vicinity of the pipeline trench.1/

Disadvantages of snow pads also exist as follows:

1. Snow must be available as a reasonable economic and environmental alternative to other materials.

2. Dependence on snow pads may impose seasonal limitations on the construction and maintenance schedule.

3. The construction season must be sandwiched between the earliest time in winter when sufficient snow is available for work pad construction and the time of spring breakup. Thus, summer, fall, or late spring construction is precluded where this type of work pad is utilized.

4. During pipeline operation, winter maintenance requires construction of a new snow pad each time maintenance is necessary and late spring, summer, and fall maintenance is impossible. Thus, in areas where considerable maintenance is anticipated, snow work pads may prove suitable for construction, but they would be normally unsuitable for subsequent operations.

5. Snow pads are difficult to construct on side hills because the quantities of snow required are greater than those required for flat or non-side hill areas. This is illustrated in Figure 15. The shaded area in Figure 15B represents the additional fill requirement for a side hill work pad as compared to flat terrain shown in Figure 15A. In addition to the larger quantities of snow required for snow pad construction on side hills, the construction process is often quite difficult. Snow is inherently a slippery material; thus, the difficulty of operating snow placement and compaction equipment on steeper side slopes is accentuated and the ground cover may be severely scarred if the snow pad construction process requires too many equipment operations with marginal cover.

1/El Paso Alaska Company, September 23, 1974. Application of El Paso Alaska Company at Docket No. CP75-96 for a Certificate of Public Convenience and Necessity, Vol. II, p. 2.1-55, Fig. 2.1-F24.

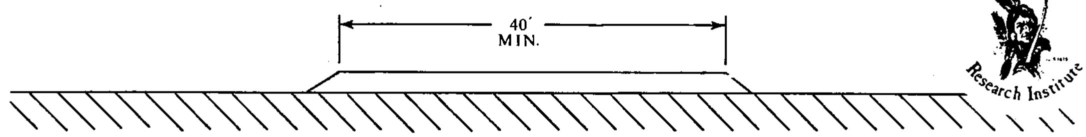

Figure 15A - Level Terrain.

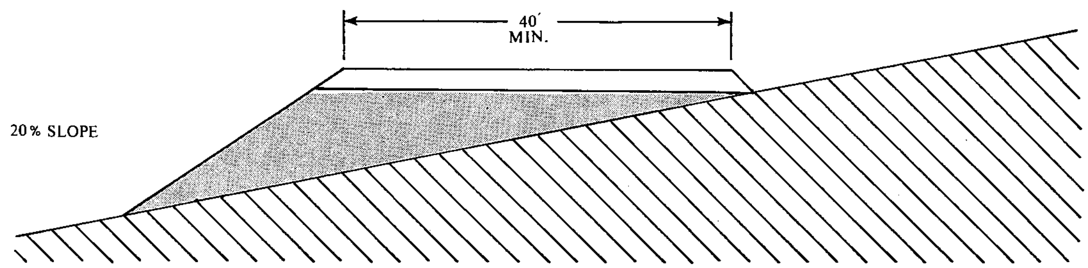

Figure 15B - Sloping Terrain.

Figure 15 - Possible Snow Pad Configurations for Winter Construction.

(ii) Earth Work Pads

The Applicant has indicated1/ several work pad sections which appear to apply to relatively flat terrain. Unfortunately, the proposed pipeline alignment traverses hills over a major proportion of the route (estimate is 65% of the route). Thus, it is not at all clear where the pipeline would be located in relation to the work pad on side hills. Several possibilities exist for cross-slope configurations of work pad, gas pipeline, Alyeska pipeline, and Alyeska work pad. Since the Alyeska work pad and pipelines are already in place, practical restraints exist with which the gas pipeline designers will be faced. These are the subject of the following discussion.

The gas pipeline work pad probably cannot be an extension of the Alyeska pad as indicated for flat ground,2/ Construction modes M3 or M4, because of a lack of construction space. If the pad is widened in the downhill direction, its height above initial ground level increases significantly and the length of reach necessary for backhoes

1/Applicant's Submission, Exhibit Z2, Sect. 1, Drawings No. APC S9-10 and 11
2/Ibid.

and for side booms in the pipe laying operation would be considerably more than the 16 foot maximum specified1/ (See Figure 16). Thus, a separate work pad would probably be necessary either uphill or downhill from the Alyeska pipeline right-of-way.

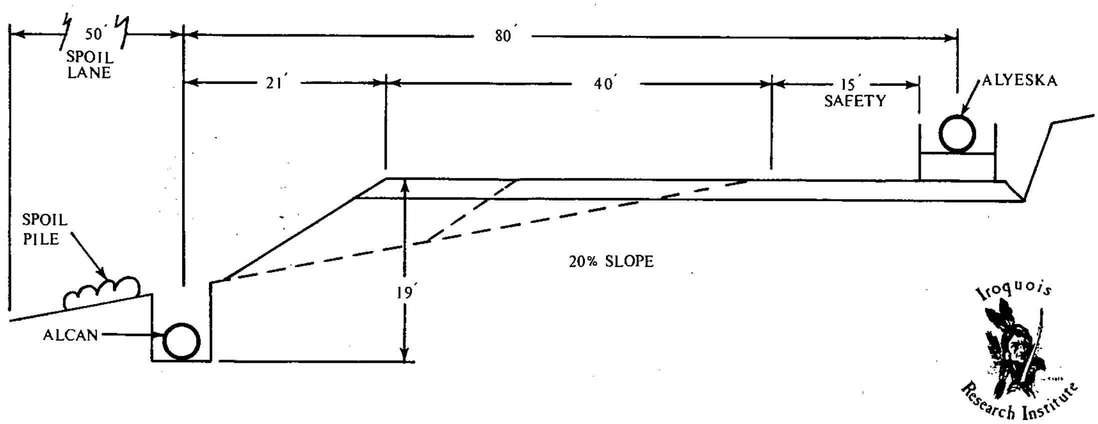

Figure 16 - Side Slopes, Alyeska VSM Configuration on Uphill Side of Cut and Fill Work Pad.

Figure 17 presents a more difficult problem than Figure 16. Here, the downhill fill depth is greater than in Figure 16. Side booms and backhoe booms would have to be longer, assuming the pipe is to be buried downhill from and adjacent to the toe of the slope. Here again, extension of the Alyeska pad on the steeper side slopes would not be feasible, and a separate pad would be necessary. If a separate pad were constructed, the gas pipeline would need to be buried adjacent to and uphill from the new work pad or beneath the uphill edge of the work pad depending on steepness of slopes.

Figure 18 is essentially the same as Figure 16. If the Alyeska work pad is widened in the downhill direction, the laying of pipe in a trench cut beneath the toe of the fill would necessitate very long side booms and backhoe booms would have to be very long if side hill slopes are of any consequence. The Alyeska pad could, once again, be widened and the gas pipe could be buried in the work pad. If the side hill slopes are anything but very gently sloping, a gas pipeline trench cut through the fill and into the underlying ground would be very deep in relation to the work pad surface. This could result in a surcharge on the gas pipe in excess of that allowable.

1/Applicant's Submission, Exhibit Z2, Sect. 1, Drawings No. APC S9-10 and 11

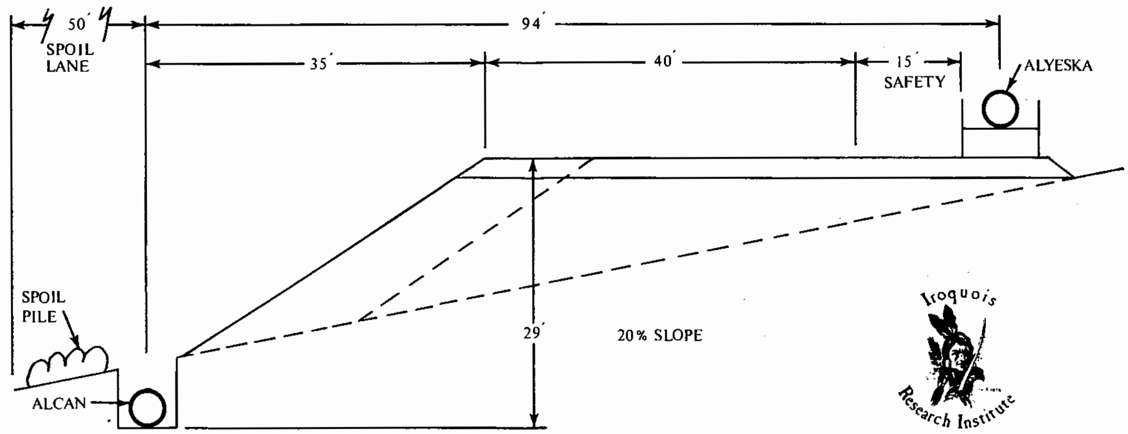

Figure 17 - Side Slopes, Alyeska VSM Configuration on Uphill Side of Fill Type Work Pad.

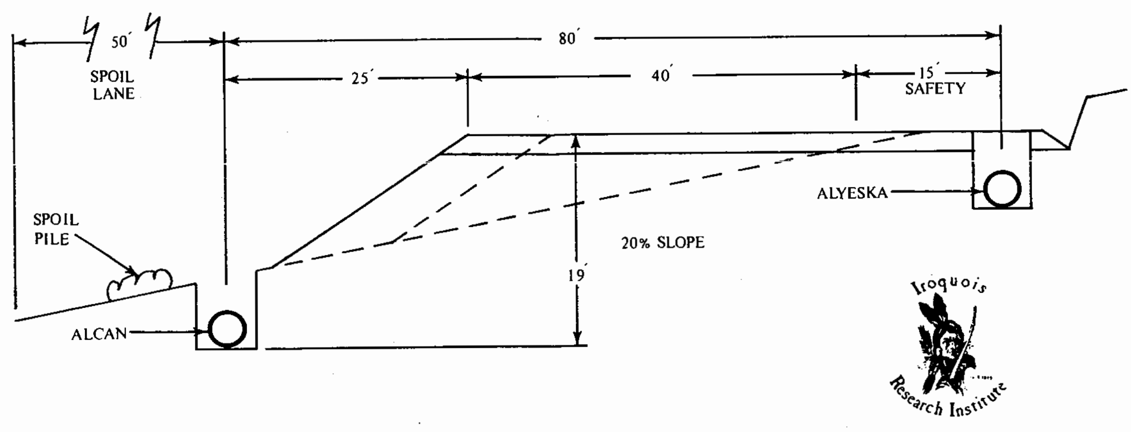

Figure 18 - Side Slopes, Alyeska Pipe Buried on Uphill Side of Cut and Fill Work Pad.

The situation as depicted in Figure 19 probably does not exist because a fill-only work pad on side hills probably occurs only where there are underlying permafrost conditions which mitigate against cutting into the hillside for the easier cut-and-fill type of side hill work pad. Thus, the Alyeska pipe would be supported by VSM.

The Applicant does not appear to have adequately considered the topic of side hill work pads. These must be seriously addressed because a large percentage of the proposed pipeline alignment lies on side hills. The Applicant's proposal indicates the use of approximately six million (5,926,000) cubic yards of borrow for extension of the Alyeska work pad. How this figure has been arrived at is unknown, but if it has not recognized the side hill additions indicated in this discussion, it is probable that the borrow requirements for work pad purposes have been seriously underestimated.

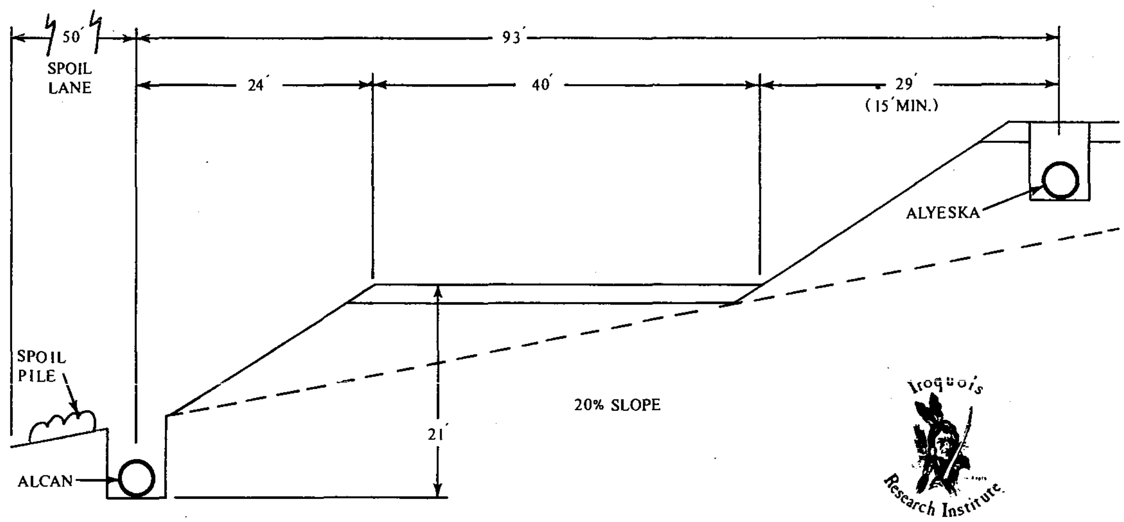

Figure 19 - Side Slopes, Alyeska Pipe Buried in Downhill Side of Fill Type Work Pad.

Work pads in the interval between Delta Junction and the Canadian Border would encounter a somewhat different set of conditions from those found in the North. An immediate concern regarding the use of the old Haines pipeline right-of-way is the presence of an 8-inch pipeline over all but an insignificant portion of the route from Delta Junction to the Canadian Border. The Haines pipe is buried from Fairbanks to approximately 10 miles south of Delta Junction. For the remaining distance to the Canadian Border, it lies principally on the surface of the right-of-way. It does not lie on one side or the other of the right-of-way but wanders from side to side. This pipe would have to be

1. removed, or

2. covered with fill and avoided by the Alcan alignment, or

3. pushed to the edge of its right-of-way whenever possible (this appears possible over the larger segment of the route).

Alternative (3) would provide a less sightly right-of-way than would the other two alternatives. In low lying areas where winter construction may provide the only attractive construction time, alternative (1) would probably be best.

That portion of the route lying between Delta Junction and the Tanana River crossing approximately 10 miles south of Tok Junction, traverses country largely underlain with gravel. The fact that highway engineers chose an alignment which consists of tangents extending in some cases to 25 miles in length, the ready availability of gravel generally along this segment, and the generally good condition of the highway surface (with some notable exceptions, i.e., vicinity of Dot Lake, north of Tanacross, south of Tok near Tanana River Bridge, and some others) attest to the generally excellent construction compatibility of this segment of the route. During the construction of the Haines pipeline, few work pad problems were encountered in that section of pipeline. The few problem areas are easily identifiable, and they consist of approximately 10-12% of the route along this segment. Along some of the Haines pipeline route in this segment, unimproved work pad soils become unstable during very wet weather and would not allow work to progress properly for various short time periods. If summer construction occurs in this entire section, a work pad would appear to be a necessity only in isolated areas because of the very serious permafrost degradation and resultant instability of the natural conditions where disturbed by several passes of heavy equipment in these isolated situations. This problem could be obviated by winter construction in problem areas. Snow work pads present a definite possibility for such construction. Since the areas of probable difficulty are rarely more than a few miles in length, late winter construction (with snow pads) in an expeditious manner would be a definite possibility. Summer cooling of the pipe in these permafrost areas appears to be necessary because the disturbance of the soil surface created by pipeline burial would certainly initiate shallow permafrost degradation in the absence of cooling. Between the Tanana River crossing south of Tok Junction and the Canadian Border, the pipeline would traverse considerably different soil conditions from those north of the Tanana River crossing. This area is generally well drained except in low lying areas. The Haines pipeline alternates between hill and valley locations. It is located in the well drained hills where such alignment does not result in excessive distances. It alternates between the northeast and southwest sides of the Alaska Highway generally seeking the better drainage, granular soil conditions prevalent on the hills. The highway has also utilized the hills to provide suitable foundation materials. Where the Haines pipeline was located in valley areas, it was done to improve and shorten the alignment, but in these areas, swamps abound.

Except for the steepness of some of the hills, the Haines pipeline constructors generally needed only a slightly improved work pad while traversing hills in this area. However, the permafrost and swampy areas did present problems, and in all of these areas, if summer construction is to occur, an artificial work pad would be a necessity for the same reasons as those mentioned for the area between Delta Junction and Tok. On the other hand, the very swampy nature of the valley segments of the Haines right-of-way may preclude the use of gravel work pads because of the unconsolidated nature of the underlying materials.

Since a good deal of the construction in the area between the Tanana River crossing and the Canadian Border would be on fairly steep hills, a work pad would be necessary not to combat permafrost, but to make trenching and pipelining possible. Soil boring data thus far is sparse but it appears from surface observation that soils are generally granular with a predominance of fine wind-deposited sands and decomposed schists in the hills.

(c) Conclusions

(i) The Applicant's Submission is incomplete without a discussion of the various work pad configurations which are illustrated and without more detailed criteria for determining which configuration would be used in a given area.

(ii) The Applicant should have considered the use of snow pads.

(iii) The Applicant should have addressed the problem of work pads on side-hills.

(iv) The Applicant's estimate of gravel requirements for work pad construction are probably extremely low.

(v) Of the entire route, the segment of the pipeline between Delta Junction and the Canadian Border should be the least difficult from the work pad viewpoint. Permafrost and/or.peat conditions exist in many low lying areas, but these do not extend over considerable distances. Artificial work pads will be required in these areas.

(vi) From surface observation, most of the route consists of granular soils varying in grain size from fine sands to boulders 1-3 feet in diameter depending on location. Much of the work can be carried out in summer without construction of a work pad. Hill terrain between the Tanana River Crossing south of Tok and the Canadian Border would require construction of a work pad, but largely of the cut-and-fill type, with a minimum of borrow necessary.

D. MEASURES TO ENHANCE THE ENVIRONMENT OR TO AVOID OR MITIGATE ADVERSE ENVIRONMENTAL EFFECTS

1. Pipeline System

b. Construction Measures

i. Civil Construction

(2) Auxiliary Facilities

(a) Applicant's Submission

The Applicant has described the auxiliary facilities construction under the headings entitled clearing and grubbing, grading, site development and road maintenance.

Clearing and grubbing performed by civil crews would be carried out at different sites such as new borrow pits, new access roads, new pipeyard sites, new campsites, station sites, O & M and meter station sites, and Alyeska work pad extension as required.

Conventional machinery would be used to clear all trees, brush and obstacles at the construction area except in areas classified as environmentally sensitive. Hand clearing would be done on such areas. Trees and brush would be cut to a maximum height of 6 inches in the work pad area, and where cutting or grading is required, grubbing of stumps would be necessary. All disposal will be performed in accordance with the government regulations.

The Applicant stated that grading work would be kept to the minimum which would satisfy erosion control specifications. Site development would be similar to the construction of work pads and all access roads, as well as haul roads, would be maintained regularly.

(b) Analysis of Submission

Although the Applicant's description of proposed auxiliary works is brief, they are considered to be appropriate. However, they lack details of specifications for the machinery and materials to be used, magnitude and areal extent of works involved and procedures for the disposal of waste material. A statement such as "Timber will be disposed of in accordance with government regulations"1/ is insufficient.

All grading works will vary depending on the topography, soil type and the nature of construction. The limitations of grading in thawed and frozen soils must be recognized. The frequency of maintenance for all roads requires careful planning.

1/Applicant's Submission, Exhibit Z2, Sect. 6, p. 22.

(c) Conclusions

(i) All auxiliary works require careful planning to minimize environmental impact. Special construction measures would be required in delicate permafrost areas where the schedule of construction activities should generally be confined to fall and early spring.

(ii) The government regulations to be followed for various auxiliary works have not been described and their limitations noted.

D. MEASURES TO ENHANCE THE ENVIRONMENT OR TO AVOID OR MITIGATE ADVERSE ENVIRONMENTAL EFFECTS

1. Pipeline System

b. Construction Measures

i. Civil Construction

(3) Material Sites

(a) Applicant's Submission

The Applicant has stated that the existing undepleted borrow pits will be used along the proposed route.1/ Also, some new quarries will be opened to minimize haul distances. According to the nature of borrow materials, scraper or front-end loader machinery will be used. Primary and secondary crushers will be utilized for the production of select backfill material as well as concrete aggregate. Materials will be stockpiled with a proper precaution against freeze-back. The Applicant has concluded that no extensive drilling and evaluation program will be required for the development of borrow pits, and that it will be possible to plan construction to provide for efficient usage of borrow material with a minimum of waste.

(b) Analysis of Submission

The Applicant's statement regarding the use of undepleted borrow pits is not supported by an engineering analysis. The backfill material and concrete aggregate are properly listed. However, no specifications as to their capacity in relation to the demand are described. The drilling and evaluation program for the borrow pits need not be extensive but careful evaluations of the available quantity of borrow materials in a particular site are needed to preclude wastage.

The Applicant provides no specifications for the quality of borrow materials to be used. Oral sources indicated that Alyeska originally developed such rigid specifications that it was impossible to comply with them. Further investigation of this point is indicated.

(c) Conclusions

(i) The machinery to be used for borrow areas is appropriate.

(ii) An additional soil-boring program would be necessary to determine the extent of the availability of the borrow material. The nature of investigation would depend upon the quantity

1/Applicant's Submission, Exhibit Z2, Sect. 6, p. 22.

of material required, areal extent of the soil deposits, and environmental impacts. This soil-boring program would also provide the data upon which specifications for fill materials could be based.

D. MEASURES TO ENHANCE THE ENVIRONMENTS OR TO AVOID OR MITIGATE ADVERSE ENVIRONMENTAL EFFECTS

1. Pipeline System

b. Construction Measures

ii. Pipeline Construction

(1) Excavation

(a) Applicant's Submission

The Applicant has indicated that ditch production (excavation) is critical to overall pipelaying production rates and that blasting techniques will be used to break up permafrost (Presumably all frozen ground) with back-hoes being used to perform the final excavation.1/

(b) Analysis of Submission

It is clear that trenching methods which are predictable and provide for acceptable production rates are a key aspect to timely and economic construction of a pipeline to be buried in frozen ground. Arctic Gas has indicated2/ that it would utilize very heavy and powerful trenchers to excavate its proposed gas pipeline trench. That equipment is apparently under development but is not yet in production.

The Applicant's proposal to use blasting techniques over a considerable percentage of its proposed alignment would require blasting of permafrost on a scale not yet attempted in North America. Alyeska experience with the blasting of its 8-inch pump station gas supply line from Prudhoe south to the vicinity of Galbraith Lake, illustrated in Figures 20 and 21, has shown that they did not have the techniques of blasting a pipeline trench in permafrost well developed. Overbreakage and trench roughness was considerable. The technology does not appear to be well developed at this time.

The proposed proximity of the Applicant's pipeline to that of Alyeska presents also the problem of guaranteeing the integrity of the Alyeska pipeline which would be in operation during the construction period of the proposed gas pipeline. The Applicant has not addressed this question. This is a very important implication if blasting techniques are used to break up frozen soil prior to excavating it.

1/Applicant's Submission, Exhibit Z2, Sect. 6, p. 24.
2/U.S. DoI, Final Geotechnic Evaluation, Alaskan Pipeline, Report No. ATR 76 (7557) - 1 Rev. 1, January 1.76, p. 43.

Figure 20 - Blasting Debris from Alyeska Gas Line Excavation

Alyeska used blasting techniques to excavate portions of a small trench for its 8-inch gas fuel line. This photograph indicates that debris was scattered up to 50 feet from the trench. A 3-foot chunk of frozen soil (center right) was thrown over 30 feet. For comparison, Alcan proposes to blast a trench 7-feet deep for a 42-inch pipeline within 80 feet of the operational exposed Alyeska oil line.

The proposed proximity of the Applicant's pipeline to that of Alyeska presents also the problem of guaranteeing the integrity of the Alyeska pipeline which would be in operation during the construction period of the proposed gas pipeline. The Applicant has not addressed this question. This is a very important implication if blasting techniques are used to break up frozen soil prior to excavating it.

If the blasting technique for trench excavation is ultimately used, very stringent controls over blasting crews would be required in order to prevent the type of overshooting shown in Figure 20 and, in turn, prevent distress or rupture of the operational Alyeska pipeline. In mobilizing for such a large construction project, the manpower requirements would be considerable; people with varying grades of talent in their specific trades are inevitably hired. For the proposed Alcan pipeline project, large numbers of men must be hired for the blasting crews to achieve rapid production trenching. At the present time, the pool of experienced permafrost and frozen ground blasters is too small to fully man this project. It will, therefore, be necessary to train manpower in large numbers for this specific purpose prior to the initiation of the trench construction. During the construction process, the blasting procedures and results must be carefully and strongly supervised by the contractors and closely monitored by both company and government inspectors. The importance of using proper blasting procedures cannot be overemphasized because of the dire consequences of even a single "shot" going awry.

Super powerful, heavy trenching equipment capable of suitably trenching all but bedrock in permafrost could make trenching on flat slopes a continuous process. This would lend itself to the production line process desirable for pipelining, if such machinery can be developed. However, if it is not available, blasting remains the only presently possible technique available for trenching in ice-cemented gravel deposits. The Applicant's scheme of locating the gas

Figure 21 - Blasting Damage to the Alyeska Gas Fuel Line

Alyeska's 8-inch gas line, some 25 to 30 feet from the trench, was covered with snow-fencing to protect it from blasting debris. The 12-inch dent in the center of this photograph is proof that the protection was inadequate. Alcan would have to provide protection, for the above ground portions of the Alyeska oil line, against similar damage.

pipeline off the work pad[1] would present some construction and work pad difficulties on side hills. However, large trenchers could not function on steep side hills and would require a work pad on which to operate. This would, of course, mean that the trench would have to be cut through and beneath the work pad.

If a dependable, high-production, blasting technique can be developed which would not have injurious effects on the Alyeska oil pipeline, certainly the major difficulties of trenching on side hills and the attendant work pad fills necessary to support trenching equipment could be minimized.

Approximately 50% of the Alyeska line is elevated because that percentage of that line traverses neither bedrock nor thaw stable soil. The opening of these areas by blasting (or any trenching technique) would admit heat to the non-thaw materials and instability would result if the excavated areas are not kept frozen. The Applicant has not addressed the question of what techniques will be utilized to prevent thaw of these types of soils during the time interval following the initial opening of the ground until the pipeline goes on line and begins to refreeze the permafrost soils excavated during the construction process.

(c) Conclusions

(i) The implications of trenching methods to be used by the Applicant are of major importance. Applicant has not provided sufficient information to permit detailed evaluation.

(ii) Precisely controllable permafrost blasting techniques for trench excavation are still being developed; the pool of personnel experienced in such techniques is small and many unknowns remain to be defined by future testing.

(iii) The potential effects of gas pipeline trench blasting upon the adjacent operational Alyeska oil line have not been determined. The reaction of experienced civil engineers to such proposed blasting is mixed apprehension and caution.

(iv) In any event, stringent controls over blasting crews and precise blasting procedures in frozen ground would be mandatory in order to permit trench blasting adjacent to the operational Alyeska oil line.

(v) The Applicant has not presented a plan for trenching and backfill which will guarantee minimum damage to permafrost during the construction and testing period.

1/Applicant's Submission, Exhibit Z2, Sect. 1, Drawing No. APC-S9-10 and 11, pp. 26-27.

D. MEASURES TO ENHANCE THE ENVIRONMENT OR TO AVOID OR MITIGATE ADVERSE ENVIRONMENTAL EFFECTS

1. Pipeline System

b. Construction Measures

ii. Pipeline Construction

(2) Crossings

(a) Foreign Pipelines

(i) Applicant's Submission

Applicant has merely stated that foreign pipeline crossings will be made in cooperation with the other pipeline owners and that adequate clearance will be maintained between pipelines.1/

(ii) Analysis of Submission

A large-scale construction project closely aligned with a very large, operational oil pipeline presents innumerable opportunities for accidental rupture of the oil pipeline. Some of the possible causes for accidental rupture of the Alyeska pipeline during construction of an Alcan gas line are as follows:

1. Uncontrolled blasting in the trenching operation
2. Uncontrolled heavy equipment striking the Alyeska pipe where it is on VSM
3. Fire weakening of VSM
4. Fire resulting from tanker truck accident on Yukon River Bridge
5. Mass wasting (land slides)
6. Accidents at foreign pipeline crossings

Due to the large amount of heavy equipment required for the total pipeline project, including additional work pad construction, it is difficult to envision that accidental damage to oil line VSM will not occur. Special provisions must be taken to assure that heavy construction equipment does not come into contact with VSM or the oil pipe itself. Special attention must be paid to those locations where construction roads pass beneath elevated segments of the pipe. Here, the oil pipeline is generally elevated high enough

1/Applicant's Submission, Exhibit Z2, Sect. 6, p. 27.

to provide for truck passage, but the passage of boomed equipment or other high equipment being transported on "low boy" trailers may be extremely hazardous. Stringent load height controls must be implemented at these points.

There are numerous points where the Alyeska pipe crosses from one side of its work pad to the other. Presumably, the Alcan pipe would cross to the opposite side of the pad at most of these locations and would, therefore, be in very close proximity to the Alyeska pipe. This is a very sensitive area during the construction (and operation) of the proposed gas pipeline. Though it is difficult to pinpoint the exact locations of many of the crossings of the Alyeska pipeline, it appears that approximately half of the crossings would be where the Alyeska line is above ground (on VSM) and about half where it is below ground.

It is emphasized that these are very large pipes and, during gas pipeline construction, the oil line will be in an operational status. When both are operational, the crossings will probably be unique because they will be two of the largest petroleum and gas lines to cross each other in the nation. In addition, many of these crossings will occur in permafrost areas. The construction of these crossings and the later simultaneous operations of these pipeline crossings would be matters of major national concern. Engineering or construction errors in the design, construction, and operation of the gas pipeline could result in disasters of significant proportions.

The Applicant has indicated few crossings of the gas pipeline with the Alyeska pipeline. On the basis of the Application as submitted, it would appear that these crossings could be made on a "custom" basis. However, direct visual observation (8/25/76) of the Alyeska pipeline, thus far in place, indicates that the Alyeska pipeline changes sides of its work pad in many locations. For example, there are in excess of ten pipeline work pad side changes similar to that illustrated in Figure 22, between Livengood and Fox, a pipeline distance of approximately 50 miles. If the Applicant's pipeline were to remain on the southwest side of the Alyeska pipeline, as indicated on Drawings Numbers APC-D9-64 through APC-D9-71, between these two locations, the Applicant's work pad would have to be added full-width, instead of incrementally, to the southwest edge of the Alyeska work pad in those areas where the Alyeska pipe follows the southwest side of its work pad. This would clearly result in a considerable widening of the cumulative work pads of the two pipelines and would bring into serious question the savings of gravel, etc., to be achieved by following the Alyeska alignment.

If, as is probable, the Applicant did not know at the time of submission the side followed by the Alyeska pipeline in relation to its work pad, the order of magnitude of necessary borrow materials for work pad additions and/or the numbers of foreign pipeline crossings has not been fully appreciated.

Figure 22 - Alyeska Pipeline-Work Pad Side Change

This photograph illustrates the point made in the text that the Alyeska pipeline is not consistently on one side of its work pad. If Alcan intends to use the existing work pad, there will be many more Alyeska pipeline crossings than are indicated in any of Alcan's exhibits. From Livengood to Fox, Iroquois counted more than 10 of these side changes in a 50-mile pipeline section where Alcan indicated no pipeline crossings. This particular photograph was taken at approximate Alcan MP 505, where Alcan again indicated no pipeline crossing. Note the vehicle damage of natural terrain in the right (north) center of the photograph. (Iroquois photo 8/26/76)

In those areas where the Alyeska pipeline is buried, conventional pipeline construction procedures can probably be utilized. Presumably, the Alcan gas pipeline would cross beneath the one already present. Individual soils designs would be necessary in order to make certain that the construction techniques and the soil properties were such that damage would not occur to the oil pipeline. In addition, however, a detailed soils and thermal analysis would be necessary to determine if the addition of a chilled pipe beneath the hot oil pipe would produce frost heaving on either pipe. Presumably, soil conditions in those areas where the oil pipeline is buried would not be permafrost problem areas, but the generation of permafrost in those areas may produce frost heaving in areas of fine-grained soils with a source of capillary water present. This would present more of an operational problem than a construction problem.

The details of Alcan crossings of the Alyeska pipeline present special problems where VSM of the latter pipeline are encountered. The combination of the spacing of Alyeska VSM and of the total width of each VSM bent places restrictions on the minimum traverse angle of crossing of the gas pipeline to avoid 60-feet spacing of 12 feet wide bents of VSM. The minimum angle of crossing, 14-1/2 degrees, would place the Applicant's pipe directly against the Alyeska VSM at both ends of the crossing span. Certainly, this would not be acceptable to Alyeska, so a greater angle of crossing would be required. This problem of "threading" the Alcan pipeline between Alyeska VSM bents is illustrated in Figure 23. It is possible that some momentum thrust problems might then occur due to necessarily sharp alignment angle changes necessary at these crossings.

It would be absolutely imperative that construction and later operation procedures be designed to preclude the thawing of soils to the extent that the thaw would produce distress to the Alyeska VSM. In the gas pipeline construction process, care would have to be taken to completely avoid physical contact with the Alyeska above-ground pipe and the VSM which support it. A suitable construction technique should be readily possible to design. Following the actual burial of the gas pipeline (assuming the foreign pipeline crossing is finally determined to be by burial), refrigeration plants may be required at each Alyeska VSM crossing site to chill the gas pipeline in the time interval between construction and the initiation of the chilled gas pipeline operation. This possibility has not been included in the Applicant's Submission.

It is doubtful that blasting methods could be used to excavate the trench for pipeline crossings. Roc-Saws have been used successfully by Alyeska in gravelly soils with a 2" gravel content of no more than 15-20% (see Figure 24). It is the consensus of several who have witnessed the operation that Roc-Saws of a larger scale could provide a useful tool for the gasline trenching, especially where blasting would be tenuous. It is clear that carefully controlled schemes must be developed for construction of the gas line where it crosses the Alyeska oil pipeline, because the construction of these crossings presents a high risk element in the construction process.

Since Alyeska pumping stations north of Atigun Pass will be fueled by the 8-inch gas pipeline which extends south along the oil pipeline, Alcan crossings of that pipeline are also a concern. A careful design of the construction techniques and of the subsequent Alcan refrigeration system to maintain the ground in the frozen state until the chilled pipe becomes operational would be necessary. Ruptures of the 8-inch line, though certainly not presenting

Figure 23 - Alyeska Pipeline-VSM Mode

This photograph taken in a northerly direction at the Chena Valve Test Site amply demonstrates the problems with which Alcan would be faced at those locations where the proposed Alcan pipeline crosses the above-ground Alyeska pipeline. The Vertical Support Member (VSM) bents are spaced at 60-foot intervals and, at this point, are approximately 10-feet wide. The angle of crossing between the pipelines would have to be greater than 15° to preserve the structural integrity of Alyeska's VSM. The 48-inch pipe is covered with insulation and a reflective metal jacket to protect it. At the VSM, the pipe jacket is an elliptic piece bolted to the Teflon coated pipe support which rests on the cross-piece. (Iroquois photo 8/14/76)

Figure 24 - Roc-Saw

Roc-Saws similar to the one shown above have been used with varying degrees of success by Alyeska for pipeline trench excavation. The machines are reportedly useful for excavating frozen gravelly soils, but efficiency decreases where gravel content is greater than 20% or more than 2-inches in diameter. These machines may be an alternative or supplement to other trench excavation methods. (With the permission of the Daily News-Miner, Fairbanks, Alaska. Photo by Holly Reckord)

so serious a catastrophe as ruptures in the oil pipeline, would result in interruption of oil pipeline operations and could, of course, present a fire and/or explosion hazard.

(iii) Conclusion

Crossings of the Alyeska pipelines (oil and gas) by the Alcan pipeline have not been adequately considered by the Applicant. This matter is much more serious than it appears the Applicant has considered it to be.

D. MEASURES TO ENHANCE THE ENVIRONMENT OR TO AVOID OR MITIGATE ADVERSE ENVIRONMENTAL EFFECTS

1. Pipeline System

b. Construction Measures

ii. Pipeline Construction

(2) Crossings

(b) Rivers and Streams

(i) General

1. Applicant's Submission

The Applicant has stated that river crossing pipe will be welded into sections on a prepared work pad area, which will depend on the geometry of the crossings (length, banks, profile). After the pad construction, the manageable pipe sections would be coated and pretested. According to the physical characteristics of the river bed, the trench would be excavated using standard machinery. Floats may be attached to the pipe to lessen the bottom drag. In smaller river crossings, the pipe may be placed in the trench with the addition of a winch on the opposite bank. During placement of the pipe, the pipe would not be allowed to buckle and each tie-in weld would be x-rayed and coated as it joins the continuous string.

The completed crossings would be backfilled with the acceptable or select materials.

2. Analysis of Submission

The Applicant's Submission lacks details of river crossings, such as minimum depth of burial below the bottom of river to prevent exposure of the pipe by scour, pipe coatings to control corrosion and elimination or reduction of the disturbances causing environmental impact by siltation or erosion. There are many sensitive river crossings along the proposed route where the aboveground construction mode has to be used by Alyeska for environmental protection, as stipulated by both the State and Federal governments. In addition, the construction schedule of river crossings may be limited to fall or early spring. It may be impractical or impossible to implement various river crossings during the significant water flows in the summer, and during icing or aufeis conditions in the winter. In some areas, river control structures may be essential to prevent possible changes in the river channels which could cause scour and erosion of the banks; uncovering sections of the pipeline where such hazards were not anticipated. Once the chilled gas is flowing in the pipeline, the creation of the frost bulb around the pipe may also change the flow pattern causing deeper scour depth and erosion. Furthermore, the uplifting of the pipe due to frost heave might cause over-stressing at the abutments. Where pipe supports are used to cross rivers, the effective embedment length of piles must allow for the scour effects and frost-heave forces. River crossings must be designed and constructed on an individual basis, considering various factors such as sub-soil conditions, hydrologic data, and environmental impact. Moreover, the impact on the integrity of the pipeline of possible river bank failures due to slope instability, liquefaction by seismic loadings, etc., must be evaluated carefully.

Where bedrock is exposed or encountered at shallow depth at the river crossings, measures to prevent pipe floatation may be accomplished by the use of steel anchors, which may be more economical than the standard concrete blocks or select backfilled materials. However, excavation in bedrock by blasting will require special attention to ensure that no existing nearby structures are affected and that the damage to aquatic biota is eliminated or at least minimized.

Figures 25 - 28 are photographs of various river and stream crossings along the Applicant's proposed right-of-way. Figures 25 and 26, photographs of the Tolovana and Jim Rivers, are typical of Alyeska's buried crossings of smaller rivers, and therefore, probably similar to Alcan's proposed river crossings. The Alyeska aerial crossing of the South Fork of the Koyukuk River is shown in Figure 27 and Figure 28 is a photograph of the northern crossing of the Tanana River at Alcan MP528.

3. Conclusions

a. Each river crossing will require individual study to determine the maximum depth of scour, surcharge load, potential environmental impact, and potential damage to the pipeline (see Figure 29).

b. Further study will be necessary for determination of the appropriate construction timing for each crossing.

c. Incorporation of existing environmental regulations, which have been applied to river crossings of the Alyeska Project by government agencies, would be beneficial to design of crossings for the proposed gas pipeline.

d. River bank stability at particular locations may be crucial in determining final alignments at river crossings.

Figure 25 - Typical Buried Stream Crossing in Progress

This Alyeska crossing of the Tolovana River at Alcan MP 398 is possibly "typical" of the proposed Alcan crossings. Concrete "saddles," used to prevent floatation of the pipe, are visible on the right (south) side of the crossing. The left side shows the pipe angling out of the buried mode where it will be connected to more pipe to be installed on the in place VSM. Piles of backfill material are located on both sides of the river. Note the vehicle damage in the upper center of the photograph. The bridge is a temporary timber structure to facilitate constructior (Iroquois photo 8/25/76)

Figure 26 - Typical Completed Buried Stream Crossing

The Alyeska crossing of the Jim River at Alcan MP 268, shown here, is a good example of a completed "typical" stream crossing prior to re-vegetation. The Alyeska pipeline is in the above ground mode approaching the river from both the near (south) and far sides. There is a gravel access road on the north side of the river. The bridge is a permanent structure, part of the haul road which was not seen in the previous figure. (Iroquois photo 8/25/76)

Figure 27 - Alyeska Aerial Crossing - South Fork, Koyukuk River

This crossing illustrates some of the problems of engineering design and construction which face the Applicant at river crossings. If the gas pipeline will be buried in the vicinity of the Alyeska crossing, extreme care must be taken to avoid undermining the piers supporting the oil line. An entirely new work pad would be required if the gas pipe is placed between the haul road (east or far side) and the existing pipeline, as indicated in Drawing APC-B9-9. If Alcan located its line on the west (near) side of the oil line, as shown in Drawing APC-D9-41, the Alyeska work pad could be used, but the rip-rap along the river banks would have to be extended. In the latter case, Alcan would be somewhat restricted in crossing the Alyeska pipe to get to the work pad even though the oil line has extra elevation at the access roads on either bank. (Iroquois photo 8/25/76)

Figure 28 - Northern Tanana River Crossing

Alyeska constructed a suspension bridge to cross the Tanana River at Alcan MP 528. Alcan's data is contradictory with regard to this crossing. One source (Drawing APC-D9-84) indicated that the crossing would be to the east (right) of the Alyeska pipeline; another source (Drawing APC-B9-18) suggested a crossing between the oil line and the Richardson Highway. In either case, an aerial crossing will probably be required. Note the side suspension required to limit sway.

Figure 29 - Alyeska "Out-of-Round" Pipe - Sagavanirktok River

The pipe pictured above was buried under the Sagavanirktok River. In the spring of 1976 some 1700 feet of it reportedly floated to the surface in flattened condition. Although there is considerable speculation, the cause of the dual failure (flattening and floatation) is not known. The incident illustrates the need for careful design and construction at each stream crossing.

(ii) Yukon River Crossing

1. Applicant's Submission

The Applicant1/ indicates that the Yukon River Bridge would be utilized for the Yukon River Crossing.

2. Analysis of Submission

The Yukon River Crossing is an extremely critical segment of the proposed gas line and Alyeska pipeline because of the vulnerability of this segment to damage of the supporting structures, because of the consequences of river pollution, and because of possible loss of operation of one or both pipes. Appropriate valving of the Alyeska pipe or both sides of the bridge reduces, but does not eliminate the potential oil pollution problem. The proposed gas pipeline should be virtually non-water polluting in the event of a failure of the gas pipe on the bridge.

In Appendix E, Iroquois Research Institute has calculated that the maximum momentum thrust produced by escaping gas at sonic velocity from a rupture with an effective flow area of one square foot would be in excess of 200,000 pounds. Certainly, the possibility exists for failures of the gas pipe with effective opening sizes of greater than one square foot. Detailed studies of the maximum possible escaping gas momentum thrust have not been made, but simple computations indicate that if gas were feeding a rupture from both pipeline directions toward the hole, and if the effective rupture area were equal to twice the cross sectional area of the pipe, gas could be fed toward the rupture at the gas sonic velocity for a time. If this were to occur, the resultant momentum thrust would equal the product of the maximum thrust per unit of area of rupture and twice the internal cross section area of the pipe. This yields approximately 3.5 million pounds of thrust, almost half the total lift-off thrust of the giant Saturn moon rocket.

The Yukon River Bridge slopes from one end to the other at a 6% slope. This unusually steep slope is illustrated in Figure 30. Bridge decks are subject to icing at times when highways on earth foundations are not simultaneously exhibiting icing conditions. If the driver is not alert to this possibility, his vehicle may, upon entering the bridge, be quickly thrown into a dangerous sliding condition. Also, at other times during the winter, bridges are, of course, slippery to traffic. The potential for a trucking accident of disaster proportions, especially of heavily-laden tanker trucks, is considerable at this location. The structural effects on this bridge of a fire of the magnitude which could be produced by accidents of single tanker trucks colliding on this bridge has not been indicated by the Applicant. Environmental impacts to the river, to the gas pipeline, and to the Alyeska pipeline might be considerable.

1/Applicant's Submission, Exhibit A, Sect. 6, APC-D9-56.

Figure 30 - Yukon River Bridge

The Yukon River Bridge has an unusually steep slope for an important bridge, as shown in the photograph above. This steep slope and winter icing conditions combine to create potentially hazardous traffic conditions. An accident would imperil any pipeline on the bridge. The road on the north (left) bank meets the river at the former terminus for the surface effect (hovercraft) ferry which carried men and materiel prior to completion of the bridge. The southern terminus is the light area near the upper right corner. (Iroquois photo 8/25/76)

In Appendix E, it is estimated that the combustion temperature of methane gas is in the order of 4000° Rankine. Appropriate valving of the gas pipeline to avoid a prolonged gas fueled fire on the bridge is consequently important. At present, proposed blocking valves are distant from the bridge. This does not appear acceptable.

It should be understood that replacement of a span of the Yukon River Bridge would require months, as this bridges is very large, unique in structural members, and remote in location. Temporary measures could probably be devised to support pipelines over a missing bridge span in a much shorter time. However, while flow is interrupted in either or both pipelines, the Nation's energy supply could be seriously reduced. The impact of cessation of these energy sources has not been addressed by the Applicant.

3. Conclusion

The Yukon River Bridge crossing is obviously an abnormally vulnerable link in both the Alyeska and the Applicant's pipelines. Because of its approximately 1/2 mile length, its sloping deck, and the icy conditions which are a fact of life at this location, the possibility for a traffic-induced disaster at this crossing is considerable. Fire resulting from a traffic accident and the momentum thrust of gas escaping from a ruptured gas pipeline appear to be the prime, major disaster concerns for structural integrity of this bridge. It is doubtful that ice-induced forces could fail the structure, since it has been designed according to exacting standards in regard to ice forces.

D. MEASURES TO ENHANCE THE ENVIRONMENT OR TO AVOID OR MITIGATE ADVERSE ENVIRONMENTAL EFFECTS

1. Pipeline System

b. Construction Measures

ii. Pipeline Construction

(2) Crossings

(c) Roads

(i) Applicant's Submission

The Applicant has indicated that road crossings will be open-cut where traffic allows and bored where traffic demands warrant.[1/] Cased pipe would be used to protect the carrier pipe as required.

(ii) Analysis of Submission

Various factors, such as soil type, traffic load, frost action and visual impact, must be considered for the design of road crossings. The Applicant has stated that the conventional methods of road crossings would be used. However, no details are given to illustrate typical cases.

Open cuts have generally been used in Alaska for other pipeline crossings with favorable results. Highway settlement problems may occur if the pipeline crosses roads in zones of high ice content soils. However, such settlement would be very localized and simple to repair. Backfill road surcharges on the pipeline must be analyzed, because road fills above the pipeline could be of some considerable depth depending on location.

(iii) Conclusion

The Applicant's proposal to use standard construction techniques for road crossings is considered adequate. The surcharge load at road crossings which may be imposed on the pipe must be evaluated with due consideration to thickness of soil cover as well as road fill material. The potential overstressing of cased or uncased pipe due to differential settlement or uplift forces must be considered in the design of specific road crossings.

1/Applicant's Submission, Vol. Z2, Sect. 6, p. 27.

D. MEASURES TO ENHANCE THE ENVIRONMENT OR TO AVOID OR MITIGATE ADVERSE ENVIRONMENTAL EFFECTS

1. Pipeline System

b. Construction Measures

ii. Pipeline Construction

(2) Crossings

(d) Dikes

(i) Applicant's Submission

The Applicant has not presented the details of the gas line's crossing of the Chena River flood control dike near Moose Creek, southeast of Fairbanks, approximate Alcan pipeline Mile Post 467.5. Alyeska's crossing of this dike is illustrated in Figure 31.

(ii) Analysis of Submission

This intended crossing is along a dike which is an important structure designed to protect the Fairbanks area from future disastrous flooding by the Chena and Tanana Rivers. Gas pipeline induced failure of the flood control structure would not be acceptable. Since the flood control structure is in place, the pipeline crossing of this structure must be designed to be compatible with it. The consequences of dike damage which would admit flood waters to the Fairbanks area could result in extreme discomfort to the local populace, probable loss of life, and extensive economic and environmental damage. Such effects occurred during the disastrous Fairbanks flood of 1967. Although population-associated direct impacts are the primary consideration in a potential flood disaster, the longer range secondary effects are no less important.

(iii) Conclusions

1. The Applicant has not noted the importance to Public Safety of the proposed pipeline crossing of the Chena River flood control dike near Alcan Mile Post 467.5.

2. The Applicant has not presented a detailed engineering plan for the chilled pipeline crossing of the Chena River flood control dike southeast of Fairbanks.

Figure 31 - Alyeska-Chena River Flood Control Dike Crossing

Located at Alcan MP 467.5, this Alyeska dike crossing is not mentioned in any of the Applicant's exhibits, although the 1"=1000' strip maps indicate that the Alcan pipeline would cross the dike at this point. This crossing could imperil the integrity of the flood control system without careful engineering design and construction. (Iroquois photo 8/26/76)

D. <u>MEASURES TO ENHANCE THE ENVIRONMENT OR TO AVOID OR MITIGATE ADVERSE ENVIRONMENTAL EFFECTS</u>

1. Pipeline System

b. Construction Measures

iii. Summer Construction Schedule

(1) In order to provide the most logical and easily understood format, this analysis follows the same subject structure as the FPC <u>Final Environmental Impact Statement</u>.

(2) General Considerations

For purposes of this analysis, it is necessary to define and set limits to the terms "winter" and "summer". In the case of Alaska, the spring and fall seasons are much compressed as compared with these seasons in mid-latitudes. The Applicant has not indicated that construction would be confined to the three calendar summer months or to periods without freezing temperatures, but has excluded the extreme portion of the winter[1]: "Pipeline construction has been scheduled for essentially those periods of the year which exclude the extreme winter climate and the associated lack of sufficient light for safe and efficient continuous spread operations."

Elsewhere in the Applicant's Submission[2] a pipeline construction schedule is shown which includes the time span April through November. Obviously this schedule for portions of the proposed pipeline route includes periods when for all practical purposes the ground is frozen and most streams are frozen over. For geotechnic considerations, "winter" is defined as the period when most soil and water bodies would be frozen in the winter condition, regardless of time on the solar calendar. For the same considerations "summer" is the period of thawing, however short it may be in some localities. On this basis, both spring and fall are much shorter periods, when thawing and freezing are beginning to occur.

Emphasis is placed on "type problem" areas some of which can be located specifically and some of which are distributed over broad geographical areas. Emphasis is also placed on analysis of "worst case" conditions both from engineering and environmental standpoints.

Inasmuch as many general and specific effects of construction in permafrost areas are known, these are not restated herein except as they may conceivably apply to the construction of a buried chilled gas pipeline. Because experience and background data for this specific set of conditions (buried chilled gas pipeline) is

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1/Applicant's Submission, Exhibit Z-1, Vol. 1, p. 1-36.
2/<u>Ibid</u>., Exhibit Z2, Sect. 6, Drawing No. APC-59-1, p. 6.

extremely limited, it was necessary to extrapolate from other applicable engineering projects. A data gap is apparent for the effects of burial of a pipeline when construction is performed during the summer season. Since many of the conclusions for the effects of a summer construction schedule are based on data from construction of facilities other than a buried chilled gas pipeline, it was deemed logical to include differences in effects for summer and winter construction.

The critical factor for construction in areas of permafrost is disturbance of the thermal balance of ice-rich permafrost, which causes either degradation or aggradation. As the principal reason for a chilled pipeline is to prevent or limit degradation of permafrost, actions which cause degradation are usually considered to have more serious consequences than aggradation. When permafrost is degraded (thawed), there are immediate effects, short term effects, and long term effects.

All of the possible effects of permafrost degradation vary by several magnitudes along the pipeline corridor. At one extreme of potentially adverse effects are areas with ice-rich, fine-textured soils on slopes and having relatively high permafrost temperatures. The opposite extreme are lower risk areas of coarse, well-drained, relatively ice-free soils on flat terrain with low permafrost temperatures. This analysis is concentrated on the first extreme. The latter extreme presents few, if any, pipeline construction constraints or risks to the environment and pipeline integrity, as compared to the first. In any case, the answers to the comparatively minimal problems, which may be encountered in the latter setting, are considered to be included within an analysis of the first.

(3) Environmental Impacts of the Proposed Action

NOTE: Subparagraph numbers in the remainder of this section are directly related to FPC EIS subparagraph numbers and subjects.

1. Climate

A summer construction schedule as compared to a winter schedule would have no significant effect on climatology of the pipeline corridor.

2. Topography

Topographic changes, which are necessary for normal pipeline construction resulting from grading in steep and rough areas, will be increased in many areas by a summer construction schedule. These increased changes in topography result as secondary effects of the greater exposure of permafrost in the warm season and increased exposure of frozen and unfrozen soils to precipitation during the summer season along many portions of the corridor.

The principal expected topographic changes would be caused by development of thermokarst terrain, initiation of solifluction and other forms of mass wasting, gullying by both running water and ice-ablation, and changes in drainage patterns. Any or all of the possible changes in topography could produce impacts to the environment and to pipeline integrity. The precise type of topographic change to be expected depends on local site characteristics.

In regard to drainage pattern changes the Applicant has stated that "Drainage patterns have been altered by the present oil pipeline construction activity, and have reached new equilibrium situations."1/ It is doubtful that most changes along the Alyeska pipeline have yet reached a new equilibrium.

3. Geologically Related Impacts

a. Resources

Both the consumption of non-renewable resources and potential impacts differ for a summer construction schedule as compared with a winter schedule. The most important difference is the significantly larger quantity of gravel which would be required for roads and work pads for the proposed method of summer construction. The snow and/or ice roads often used in Alaska and other Arctic regions have unique impacts but do not consume a non-renewable resource.

The impacts arising from use of gravel go much beyond the actual amount of gravel used, and occur at:

(1) The pit or streambed from which the gravel is obtained;

(2) Along the routes over which the gravel is transported; and

(3) At the site of utilization.

The severity and duration of the impacts of gravel use vary with the three above areas, with the "worst case" being the acquisition of gravel from a streambed during a critical life stage for important fish species. State and Federal officials have not permitted this in the case of the Alyeska pipeline. Total gravel resources of the State of Alaska are impressive but often locally limited. This resource is not uniformly distributed, and as a result the real impact of use must be calculated on the basis of use of the most acceptable source, i.e., acceptable in terms of costs and environmental impact.

The use of ice and snow roads and work pads also have impacts, but are usually less severe or nil and not as long lasting as for gravel.

1/Applicant's Submission, Exhibit Z-1, Vol. 1, Sect. 3, p. 3-10.

Regardless of season of construction, there is distinct advantage in having permanent gravel roads and work pads available for use in routine maintenance or for making emergency repairs to the pipeline during the summer operation phase.

b. Permafrost

The immediate and primary effects of permafrost degradation are the physical processes of thaw consolidation, soil erosion, mass wasting, changes in drainage patterns, and solifluction. These effects in turn produce secondary effects to the physical and biological environment and affect pipeline integrity. All of the primary effects of permafrost degradation are, to some degree, also natural processes which occur from natural causes, such as stream ice jams or forest fires. Pipeline construction activity, and, in particular, summer construction as compared with winter construction, will accelerate and magnify the processes of permafrost degradation. These primary effects are well known; the secondary effects which may accrue to the environment and to the pipeline are not so well known.

c. Frost Heave

The proposed summer construction schedule (as opposed to a winter schedule) may create conditions for greater potential frost heave effects. This could happen in one or both of two ways. One way is that ice-rich soils suffer thermal degradation, causing a deeper thaw bulb. If there is poor drainage, saturated soils increase in volume upon freezing. Portions of the pipeline will be subjected to at least two annual freeze-thaw cycles before it is operationally chilled and the soil becomes permanently refrozen around the pipe. A second reason for greater potential frost heaving as a result of summer construction is the continuous supply of moisture from the backfill to the surrounding freezing soil. This condition would not be as serious for winter construction.

d. Erosion and Mass Wasting

Both primary and secondary erosion will likely be more severe for a summer construction schedule than for a winter schedule. Summer disturbance of the unfrozen active layer will expose significantly larger quantities of loose soil to wind and running water. For some areas, the erosion hazard would be most severe if construction took place during spring thawing when soil is still frozen and impermeable and water available from thawing snow is at a maximum.

Alaska is no exception in that erosion would be most severe on steep slopes with unstable soils. However, in areas with ice-rich permafrost and slopes, the degree of slope which might be affected by erosion and mass wasting is much less than in temperate regions without such conditions. Even under natural conditions, there are active areas of erosion and various forms of mass wasting of relatively shallow slopes, which would not present problems for pipeline construction in non-permafrost zones.

Where solifluction flow of the active soil layer is likely to be a problem, the potential for both environmental impact and effects on pipeline integrity are likely to be as serious as those from small landslides and other forms of erosion and mass wasting. Solifluction can and does occur on relatively flat slopes and is insidious and difficult to predict. There are some areas of naturally occurring solifluction along the proposed pipeline corridor which must be identified and avoided in determining final alignments.

The marginal conditions for occurrence of solifluction are the areas of greatest concern when considering the different effects of summer versus winter construction. As with other potential impacts, the impacts of solifluction are sequential to degradation of permafrost or other actions which change the balance of physical forces in soils and unconsolidated sediments. Under marginal conditions, initiation of change is the critical point; and under some conditions, the initial changes will undoubtedly be greater for summer construction than winter. An example of the additive effects of summer construction would be the conversion of a minor skin flow to deeper seated solifluction by increasing the depth of the active layer.

In permafrost zones, erosion and mass wasting are processes which, once begun, are difficult or impossible to control or prevent. Under a "worst case" condition of excavating a pipeline trench on a slope having ice-rich permafrost during a period of high air temperatures, the melt water itself may be sufficient to initiate a form of erosion which is serious and difficult to control. In this case, the flowing melt water could cause both ordinary and thermal erosion; wherein, an erode-thaw-erode process is initiated which continuously exposes new permafrost surfaces.

In the event that fine-textured soils are dry during the construction period, wind erosion of excavated and other disturbed soil areas could be significant unless control measures are implemented. The soils-climate setting for large portions of the proposed pipeline route is conducive to large scale dust problems from vehicle pertubations, whether or not winds are of sufficient volocity to be a primary erosion agent.

4. Soils

The differential effects on soils of a summer versus a winter construction schedule are primarily those attributable to potentially greater erosion and mass wasting for the summer schedule. A single advantage of the summer schedule that would reduce impact to soils may be that in some areas where construction takes place near the beginning of the summer season, revegetation and restoration could be initiated during the same season.

The effects of soil manipulations on soil structure degradation are different for the frozen and unfrozen states. When frozen soil is excavated or otherwise manipulated, soil aggregates are broken down primarily by fracturing. Manipulation of unfrozen soils which have high water content, on the other hand, may cause puddling and nearly complete loss of natural soil structure. Destruction of natural soil structure may have either a beneficial or neutral effect on engineering properties but is usually considered detrimental to several soil physical properties which affect the ability of the soil to support plant growth. The end result is to decrease drainage and aeration and consequently the growth of many plant species.

Since many soils in Alaska and other permafrost regions are essentially massive or structureless or have only very weakly developed pedogenic structure, it may be argued that degradation of structure is of no consequence. On the other hand, even the weakly developed soil structure in the active soil layer may be essential to the plants growing on it, and the effects of soil structure degradation would be even more pronounced because the structure is weak and easily altered.

5. Water Resources

a. Surface Water

The proposed pipeline alignment crosses approximately 133 perennial streams in the continuous permafrost zone and 71 in the discontinuous permafrost zone. A potential exists for impacting surface water resources at each stream crossing and at other places. The potential impacts vary for stream classes and for individual streams, but for all streams and other surface water bodies may be categorized as affecting either water quality or the hydrologic regime, effects which are usually interrelated. In many cases, the effects on surface waters will have secondary and even tertiary effects, such as alteration in stream-biota and then alterations in stream ecosystems.

In addition to the already discussed indirect effects of erosion and mass wasting on producing drainage pattern changes and water pollution by sediment, stream crossings are points where hydrologic and pollution impacts can be direct and immediate. Both the method and timing of construction for stream crossings are critical for individual streams, and for different reasons for various stream categories. The Applicant has recognized that stream crossings present special problems of protecting fisheries and avoidance of changes in the hydrologic regimes of streams.1/ The Applicant proposes to study each stream on an individual basis and determine specific techniques for construction at each crossing and determine specific times when crossing construction would have least adverse impacts.

1/Applicant's Submission, Exhibit Z-1, Vol. 1, pp. 4-6 to 4-8.

b. Groundwater

Potential impacts to groundwater are greater for a summer construction schedule than for a winter schedule. These greater impacts would accrue primarily from interception of ground water in trench excavation and the need for trench dewatering. The trench dewatering process could add sediment and a small quantity of nutrients to local surface waters in the absence of proper mitigating procedures.

c. Water Quality

In areas where water erosion will be a problem, deterioration of water quality from excessive quantities of suspended sediment can also be expected. Water quality deterioration from suspended sediment will not be confined to areas of permafrost, but can be expected to be much greater for a summer construction schedule than for a winter schedule. Excavations in or near major streams are obvious critical points for affecting water quality. Water quality degradation impacts are discussed in further detail in the following section on impacts to aquatic biota.

6. Aquatic Biota

The potential to affect aquatic biota is site-specific and time-dependent for disturbance, whether within the summer or winter season. Construction in or near surface water bodies poses both hydraulic and physio-chemical problems. For example, in the Applicant's analysis of biota problems which may be encountered in streams,[1/] the times when construction should be avoided for 21 streams ranges from June through February. This does not imply, however, that all stream crossing construction should take place in March, April, and May. It does imply that adding extra loads of sediment, biochemical oxygen-demanding substances, and physical disturbances of various sorts, may have critical effects on fisheries in some streams at any time, and critical effects in some streams only at specific times.

Fisheries biologists have observed and studied the streams traversed by the Alyeska pipeline for several years. The times and locations of both fish spawning and fish migration are well known. However, there have been no similar intensive studies of the streams between Delta Junction and the Yukon Border which Alcan proposes to cross. Such studies would be necessary prior to finalization of the stream crossing construction schedule.

7. Vegetation

Summer construction as compared with winter construction could have both more primary and secondary impacts on vegetation. The most obvious reduction of impacts for winter construction occurs because of

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1/Applicant's Submission, Exhibit Z-1, Vol. 1, pp. 3-6 to 3-8.

the potential for use of snow work pads which in some cases can leave low-growing vegetation essentially unaffected.

In many cases the secondary effects of summer construction on vegetation would be more severe than the primary effects. This occurs because of the greater potential for summer construction to degrade permafrost and initiate secondary erosion and mass wasting.

Spring or early summer construction does offer an advantage in that some areas could be revegetated immediately after burial of the pipeline.

8. Wildlife

The potential effects of summer versus winter construction on wildlife are mixed. Alaska has both resident and migratory species of birds and animals, and resident species which are also migratory within the proposed pipeline corridor.

Overall, construction in summer would impact more species and more individuals than would winter construction, for the simple reason that greater numbers would be in the corridor in summer. For some species there would be an additive impact from interference with critical points in life cycles, such as nesting, molting, spawning, etc. More species nest and rear young in summer than in winter.

Caribou represent a special case in which wildlife could be disturbed at any time during the year if they were in the area during construction. The Arctic Caribou herd, for example, overwinters south of the Brooks Range, calves on the North Slope, and migrates between these areas during spring and fall. In this case, disturbance could be mitigated by having construction take place in the respective areas when caribou were predominantly absent.

When all biotic factors are considered collectively, a conclusion is reached that all impacts to biota cannot be avoided by having construction take place during any one period for the entire proposed pipeline. Disturbances to wildlife could be minimized by construction scheduling which would avoid the most important and sensitive species at critical times.

9. Ecological Considerations

In view of the many primary, secondary, and tertiary impacts which may be increased by summer construction as compared with winter construction, a logical conclusion is that potential for ecosystem upset is also greater for summer construction. This is especially true for the tundra on the North Slope.

Although it cannot be quantified, the increased ecological disturbances from summer construction would occur for two general reasons:

a. Greater degradation of permafrost and the resulting secondary and tertiary impacts of erosion, sedimentaiton and degradation of habitat.

b. Summer construction would disturb greater numbers and species of fish and wildlife at more critical times in their life stages.

14. Air Quality

A potential for formation of ice-fog during the winter season exists for some geomorphological settings in which air pollutants from exhaust emmisions and other sources could be trapped by atmospheric inversions. Fairbanks is the outstanding example of a place where this form of air pollution has been a chronic problem.

In contrast to potential ice-fog pollution problems for the winter season, fugitive dust may be an important air pollutant for some situations during summer construction. Fugitive dust is, however, much more easily controlled than ice-fog. One method, among others, of controlling road dust by applying waste petroleum products, used by Alyeska, may cause soil and water pollution.

16. Comparative Analysis of Effects of Buried Chilled Gas Pipeline in Different Settings

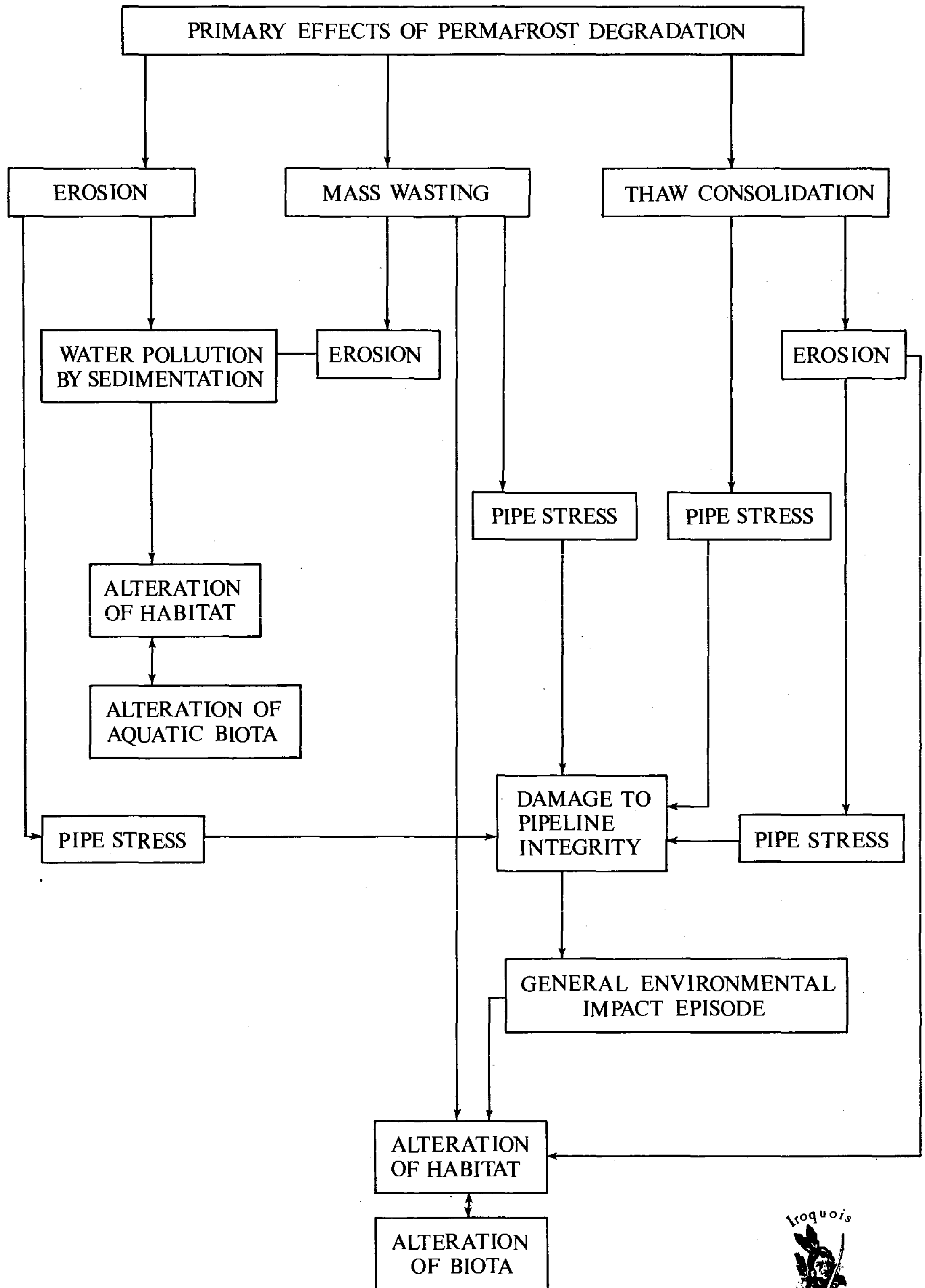
a. General Considerations

"Typical" and "worst case" examples of physical and thermal regime settings in which the proposed pipeline may be buried are discussed in this section. The scenarios are illustrated by cross sections and longitudinal sections of the pipeline buried in various conditions of permafrost and geomorphological settings.

Figures 32 and 33 are flow charts showing the primary, secondary, tertiary, and ultimate effects of permafrost degradation and aggradation. These flow charts are intended to show how initial actions affect pipeline integrity and the environment. Although the principal differences in the effects of a winter versus a summer construction schedule are those affecting permafrost degradation, the number of variables and unknowns is very large, and it can not be assumed that construction timing at a particular place will have no effect on aggradation of permafrost.

Stream crossings are recognized as both engineering and environmental "problem areas" and are therefore included here for comparison with other critical areas. Where timing is critical for construction of stream crossings for reasons other than effects on permafrost, the construction of stream crossings will affect overall construction scheduling.

The sequential effects of permafrost degradation shown in Figure 32 are assumed to become progressively more severe and



Iroquois Research Institute

Figure 32 - Effects of Permafrost Degradation.

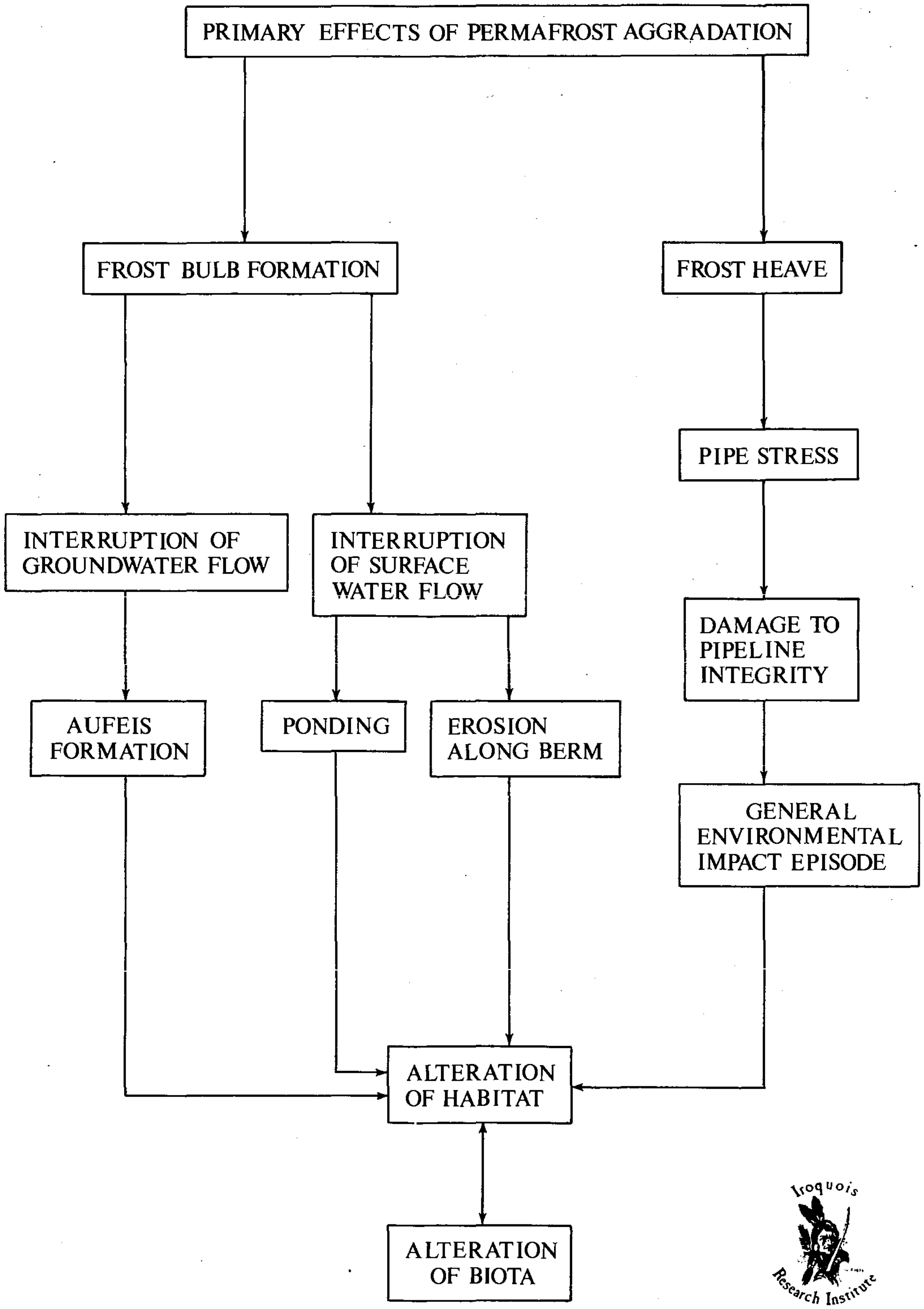


Figure 33 - Effects of Permafrost Aggradation.

difficult to arrest, although probabilities of the ultimate disaster of pipeline rupture accompanied by explosion and fire do not increase. There would be, for example, absolute certainty that some ice-rich permafrost will be thawed if the pipeline is constructed in summer, but one or more occurrences of thawing would not necessarily result in an equal number of general environmental impact episodes. In the following sub-sections, the probabilities for the occurrence of the effects outlined in Figures 32 and 33 are discussed for different critical settings.

b. Pipeline Buried in Ice-Rich Permafrost on Level Terrain, With and Without Talik Layer

These two settings are illustrated by Figures 34 and 35. The principal effects will be thaw consolidation, ponding, possible pipe flotation because a trench on level terrain traps water, and subsequent frost heaving when the thaw consolidated soil refreezes and expands. Depending on soil texture and water content, the talik layer may feed excess water to the construction trench which would subsequently freeze and increase frost heaving. Possible mitigating measures for this setting are:

(1) Winter construction

(2) Backfill surcharge followed by maintenance additions of granular material until pipeline is chilled and the backfill and berm become frozen.

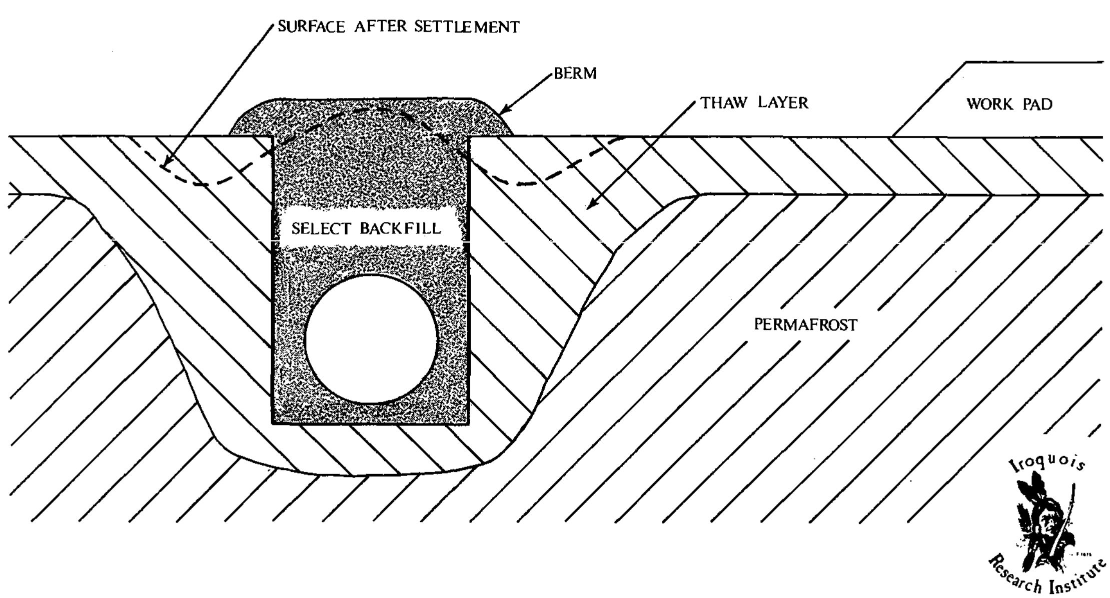


Figure 34 - Cross Section of Buried Pipeline on Level Terrain with Ice-Rich, Fine Textured Soil. Depicted in Fall after Mid-Summer Construction.

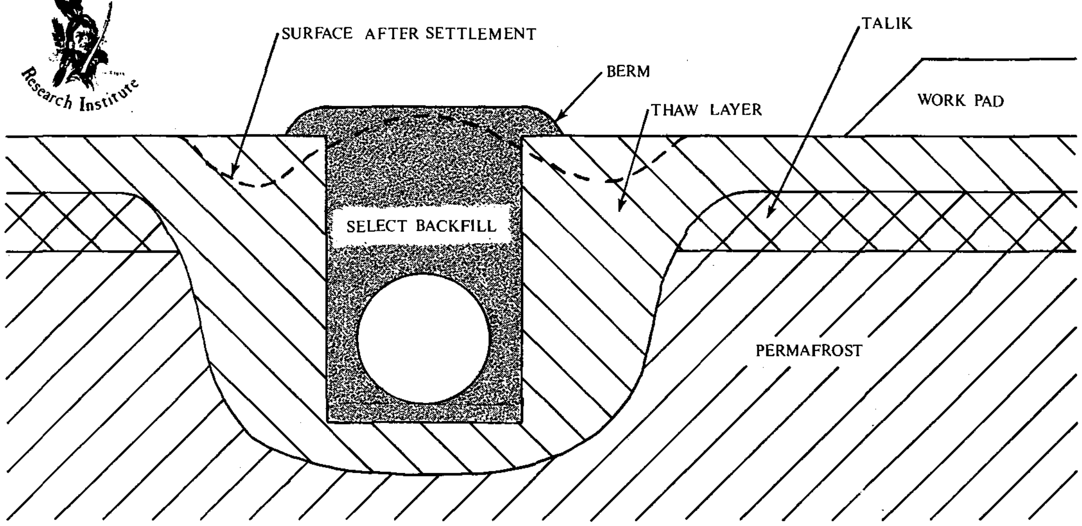


Figure 35 - Cross Section of Buried Pipeline on Level Terrain with Ice-Rich, Fine Textured Soil Containing a Talik Layer. Depicted in Fall after Mid-Summer Construction.

c. Pipeline Buried in Ice-Rich Permafrost in Side Hill Cut

This setting, illustrated in Figure 36, probably represents the most severe set of conditions which may be encountered other than at some stream crossings. The possible occurrence of a talik layer in this setting would further complicate matters, depending on its location with respect to the pipe and work pad. The primary concern here is maintenance of slope stability, both during and following construction, against the forces created by thaw consolidation, erosion, and mass wasting. Solifluction downslope from the pipe is a major concern because stress forces would be directed perpendicular to the longitudinal axis of the pipe. An extremely critical point is the cut slope, where stability is of concern on both a short-term and long-term basis. Making a flatter cut-slope is an incomplete solution to stability as this action would expose additional area of permafrost to thawing.

After the pipeline is chilled the frost bulb would have some stabilizing effect, at least against the development of deep-seated creep. If a talik layer were present in the cut slope, aufeis formation could be a problem during construction, after construction, and during the operating phase of the pipeline.

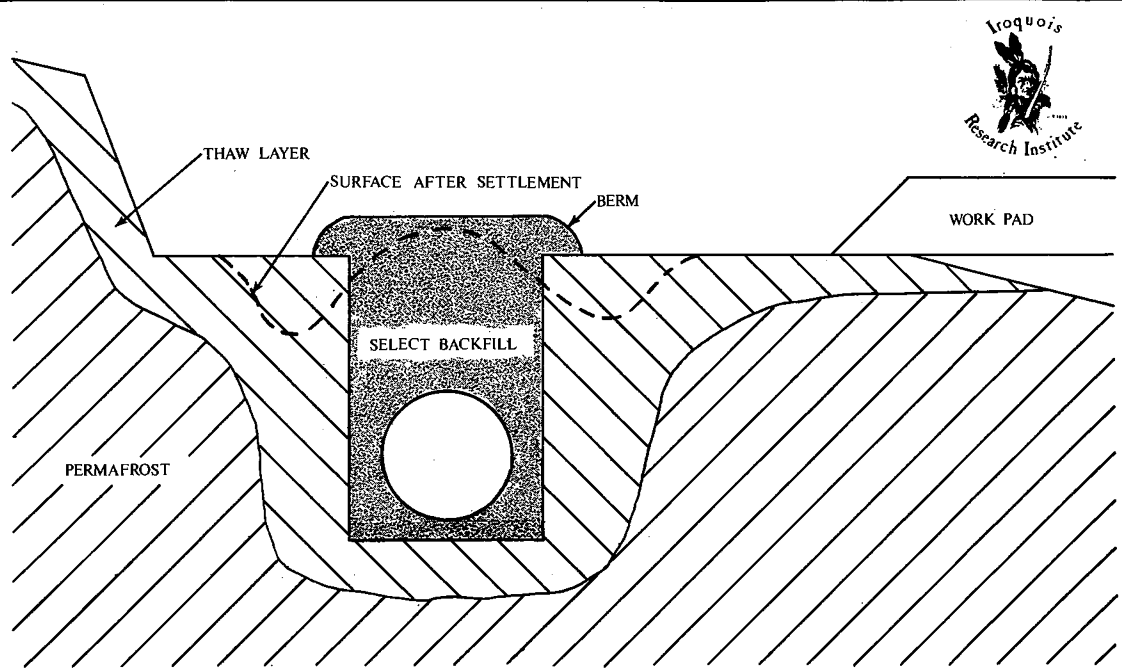


Figure 36 - Cross Section of Buried Pipeline in Side Hill Cut in Ice-Rich, Fine Textured Soil. Depicted in Fall after Mid-Summer Construction.

As mitigating measures are few and expensive for this setting, avoidance of the setting in alignment is an obvious first choice. Winter construction might avoid slope failure during construction and enable reinsulation of frozen ground before the next summer.

d. Pipeline Buried in Discontinuous Permafrost Containing Large Ice Mass Immediately Under Pipe Trench

The ice mass shown in Figure 37 may be relict or occur because of particular conditions in the subsoil. Construction during summer would likely result in melting of the ice mass, loss of pipe support across the void, and subsidence of the backfill. The seriousness of this problem depends on the lateral extent of the ice mass, and the length of the pipe which would be unsupported.

Mitigating measures include winter construction or detection of the ice mass followed by deliberate thawing and filling of the resulting void with granular backfill.

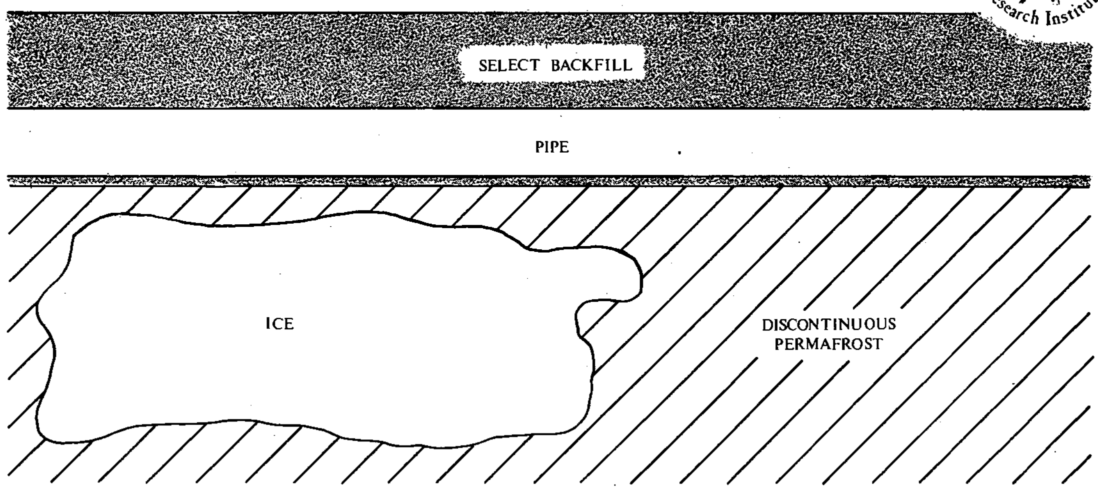


Figure 37 - Longitudinal Section of Buried Pipeline with Underlying Ice Mass in Unfrozen Soil. Depicted in an Area of Discontinuous Permafrost.

e. Pipeline Buried in Discontinuous Permafrost Zone at Boundary Between Frozen and Unfrozen Soil

This setting (Figure 38) which is also applicable to a boundary between thaw stable and non-thaw stable permafrost, would most likely occur at a discontinuity in either subsoil properties or vegetative cover, and has potentially more serious implications for pipeline integrity than the case of the ice mass discussed above. In this setting, a critically long span of pipe might be unsupported or poorly supported. These conditions are most likely to occur where the permafrost is warm and summer construction would have maximum effect in thawing permafrost. Two mitigating procedures are possible:

(1) Construction during the winter season to preserve the permafrost;

(2) Excavating the trench to greater than normal depth and replacing the permafrost with granular backfill.

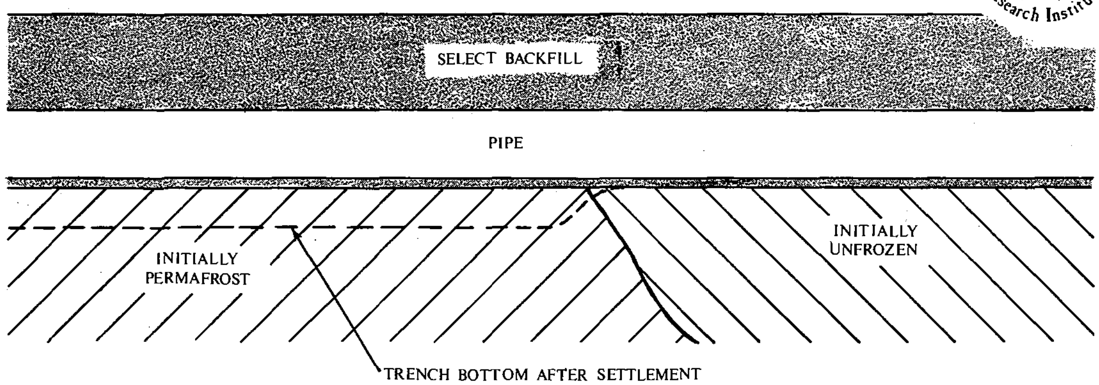


Figure 38 - Longitudinal Section of Buried Pipeline Traversing Ice-Rich, Fine Textured Permafrost and Unfrozen Soil. Depicted in an Area of Discontinuous Permafrost.

f. Pipeline Buried in Continuous Permafrost Under Stream Which Freezes Completely

This setting, shown in Figure 39, could also occur in the discontinuous permafrost zone with small streams which do freeze completely in winter. This setting does not present serious problems during construction unless there are environmental impact limitations for summer construction. The principal problem here may be the ice dam created in the stream bed during chilled operation of the pipeline. The ice dam could cause retarded break-up at the crossing in spring and advanced freeze-up at the crossing in fall. In both instances abnormal local flooding may be caused, impacting habitat, biota, and pipeline integrity.

g. Pipeline Buried Under Frozen Stream With Unfrozen Pervious Aquifer

This setting, shown in Figure 40, is most likely to occur with major streams north of the Brooks Range and smaller streams in the southernmost portion of the proposed pipeline corridor. The problems arising under these conditions are similar to those which may occur in the above setting, except that the frost bulb may block water flow in the aquifer in winter. The likely result in this case may be break-out of water to the surface and formation of aufeis. Construction in winter would be difficult because of the aquifer.

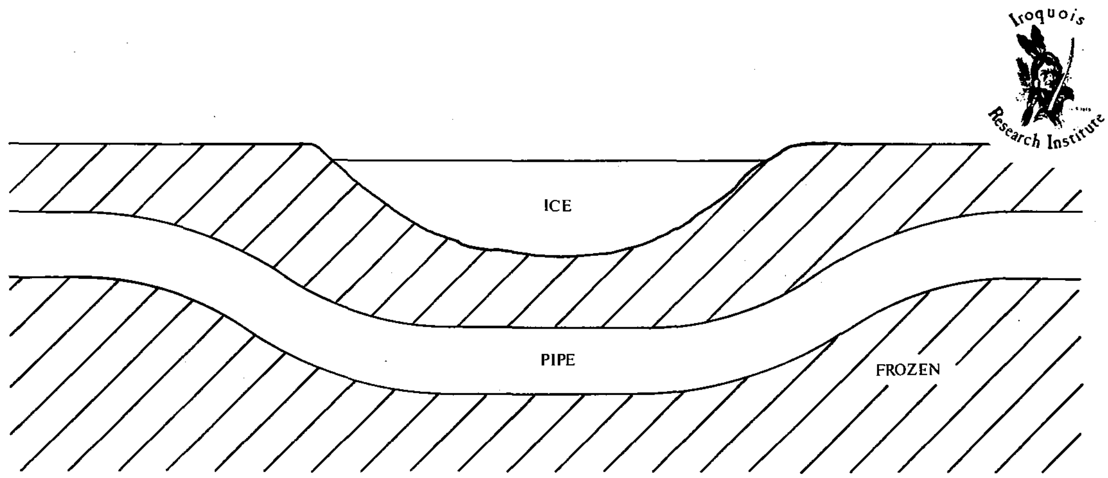


Figure 39 - Longitudinal Section of Buried Pipeline at a Frozen Stream Crossing. Depicted in Mid-Winter prior to Operation of Chilled Pipeline.

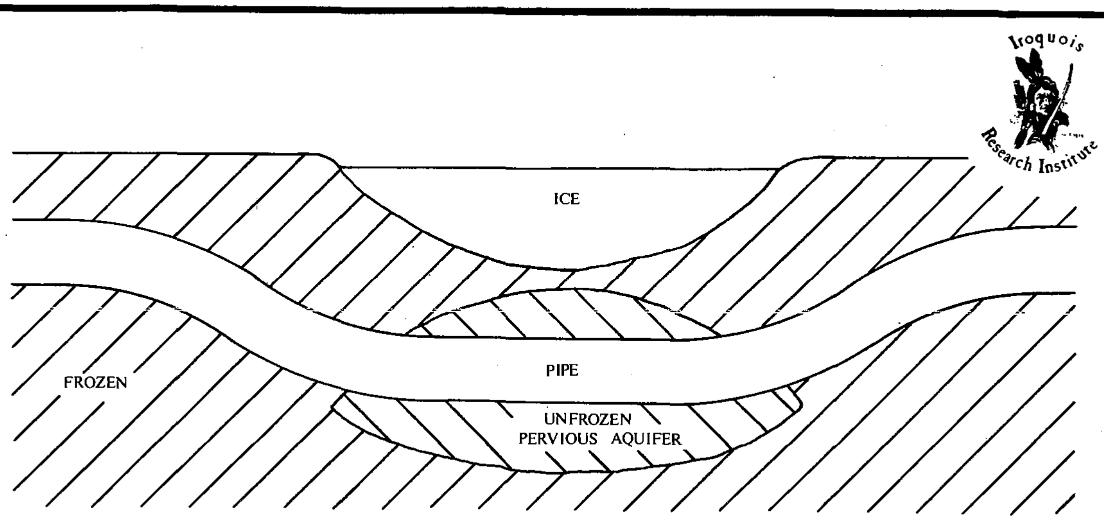


Figure 40 - Longitudinal Section of Buried Pipeline at a Crossing of a Frozen Stream with an Underlying Unfrozen Pervious Aquifer. Depicted in Mid-Winter prior to Operation of Chilled Pipeline.

h. Pipeline Buried Under Stream Which Does Not Freeze Completely and Contains Unfrozen Aquifer

This setting, Figure 41, is most likely to occur along major streams in zones of discontinuous permafrost. Construction here in winter would be practically impossible. The major difference in effects of operating a chilled pipeline in this stream setting as compared with others, would result from the frost bulb blocking under-ice water flow. The consequences may be formation of aufeis on and adjacent to the stream and interference with overwintering fish.

Possible mitigating measures are an aerial crossing, deeper burial of the pipe below the stream bed, or late winter construction. Not illustrated is a setting wherein the aquifer shown in Figure 41 is instead an impervious stream bed. In this case, the formation of an ice dam would be more certain to have adverse effects.

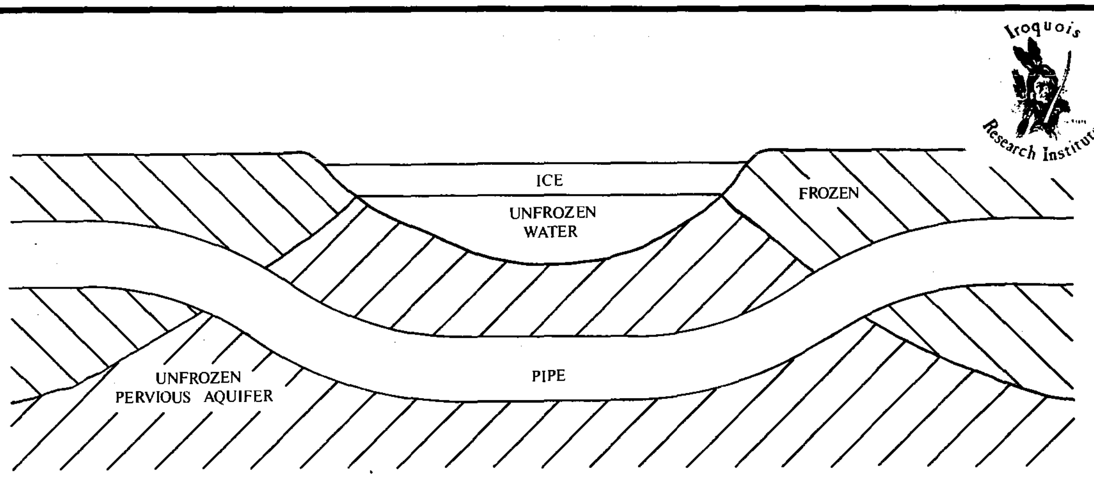


Figure 41 - Longitudinal Section of Buried Pipeline at a Crossing of a Stream with Ice Cover and Underlying Unfrozen Pervious Aquifer. Depicted in Mid-Winter prior to Operation of Chilled Pipeline.

E. UNAVOIDABLE ADVERSE ENVIRONMENTAL IMPACTS

1. Applicant's Submission

The Applicant has provided no statistical data that can be used to estimate the probability of pipeline rupture. Statistics taken from another source[1/] on the frequency of pipeline ruptures in the United States are shown in the following table.

TABLE 4 - INCIDENTS OF RUPTURES IN THE OPERATION OF GAS TRANSMISSION LINES, 1970-72

(36-Inch Diameter & Larger)

	1970	1971	1972	Total	Average
Miles In Service	12,191	13,136	13,201	38,520	12,846
Ruptures	1	2	0	3	1
Ruptures per 1000 Miles	0.082	0.152	-	-	0.077

In addition, reports obtained from three major Canadian gas transmission systems operating approximately 7,000 miles of 30-inch to 42-inch pipeline for a period of 17 years show a total of 10 ruptures, equating to a probability of 0.084 ruptures per year per 1000 miles.[1/] This compares favorably with the average value of 0.077 ruptures per 1000 miles as shown in the above table since, approximately half of all reported ruptures were caused by outside sources, particularly by equipment operated by outside parties. The incidence of rupture was stated to be lower in uninhabited areas than in inhabited areas.

The Applicant stated that the major consideration regarding pipeline integrity would be a large leak or a break of the pipe. Therefore, as part of the maintenance plan, pipeline repair equipment would be classified as standby equipment. It would be located at the Happy Valley and Fairbanks District Bases. A repair crew could be dispatched from the maintenance base closest to the line break, and any additional personnel required would be flown in from the other District.

The Applicant has stated that breakdown of the various components of the pipeline system, other than major pipe ruptures, could cause environmental impacts of several types. A component of the system could fail and cause shutdown of the entire system or a compressor station failure might require partial shut down. In case of a line failure, gas might be vented to relieve excess pressure in other sections as well as

1/U.S. DoI, Final Geotechnic Evaluation, Alaskan Pipeline, Report No. ATR 76 (7557) - 1 Rev. 1, January 1976, p. 245.

to clear the section in which the failure had occurred. Gas venting may impact the local atmosphere, particularly during a winter inversion period. Should the component failure result in leakage, such leakage might damage the vegetation. Change of albedo at the surface as a result of the chemically damaged vegetation could affect the soil thermal regime.

Repair of components would require access to the location of the damage. Should access not be available along the work pad, damage to vegetation could result from vehicular traffic using emergency roadways.

2. Analysis of Submission

The average statistics presented above show 0.084 ruptures per 1000 miles per year. The Applicant's Submission proposes a pipeline of 731.4 miles in length. Based on the above statistics, this line might experience

$$\frac{0.084 \times 731.4}{1000} = 0.061 \text{ breaks}$$

per year or one break every 16 years.

The proposed pipeline will be operated in an environment which will bring to bear a number of imponderables with respect to pipe integrity. These include external loadings created by the adverse environment which have been estimated, but no corroborative experience was presented in the Submission for use in developing a confidence level for the estimates. An important environmental factor is the effect of low temperatures on the toughness of the steel composing the pipe. Each of these considerations has been discussed at length in other sections. They do have a very real effect on the confidence with which one would accept the above statistic that one rupture would occur, on the average, every 16 years.

Steps to mitigate the effect of these imponderables can be taken. Generally they may all be included in the term "factor of safety." The factor of safety can be improved by:

a. Increasing the pipe wall thickness of all field pipe from 0.600 inch to 0.625 inch. This latter thickness is a standard thickness for 42-inch diameter X65 grade pipe. The 0.600-inch wall thickness proposed by the Applicant is not listed in the API 5LX recommended pipe sizes; the 0.625-inch thickness is listed. As the average strength of the pipe is directly proportional to wall thickness, increasing the thickness will give the pipe increased ability to withstand overpressures and higher loads. Corrosion of the pipe results in an effective reduction in wall thickness. Increasing the original thickness tends to extend the period before extensive corrosion would terminate its useful life.

b. Increasing the pipe wall thickness (above that required for line pipe) at river crossings, road crossings, pipeline crossings, under work pads, and in the vicinity (within 300 feet) of block valves, meter stations, and compressor stations.

The need for a critical look at the performance of API X65 steel pipe for chilled gas line use in the Arctic with possible emergency shut downs under full operating pressure while exposed to Alaskan winter temperatures has been discussed in other sections. As the prime material property involved is brittleness, an increase in wall thickness does not increase toughness (decrease brittleness). A choice of a more suitable steel composition, suitable heat treatment, testing procedures which include below freezing temperatures, and a welding program suitable to the specific conditions, could considerably increase the probability that the pipeline would withstand the rigors of its environment.

A description of all overpressure control and safety devices and safety stop valves would allow an estimate to be made concerning the impact of such equipment on the integrity of the pipe.

3. Conclusions

a. Some probability of rupture of the pipeline would always exist, but until more specific and quantitative information is presented on environmental effects, on the properties of the pipe material, and on methods of safety control, the level of risk of rupture cannot be quantified.

b. The most significant identified risk is the possible brittle failure of the pipe when strained at low temperatures.

c. Except for brittle failure conditions, the factor of safety could be increased for most conditions by increasing pipe wall thickness.

d. An additional increment in reliability improvement can be gained by increasing wall thickness above the nominal thickness at all exceptionally hazardous locations such as crossings of various types and at above ground projections such as block valves, meter stations, and compressor stations.

G. IRREVERSIBLE AND IRRETRIEVABLE COMMITMENTS OF RESOURCES IF THE PROPOSED ACTION SHOULD BE IMPLEMENTED

1. Damages from Natural Catastrophe or Man-Caused Accidents

a. Applicant's Submission

The Applicant has mentioned several potential modes of environmental damage that could result from natural or man-caused accidents. Of major concern are the consequences of pipeline ruptures. Design and protective measures would be employed in order to minimize fatigue and failure potential. The following are excerpts from the Applicant's Submission.

> Fire and pipeline ruptures are the two types of potential accidents which would result in the most impact on the environment. In the unlikely event of a pipeline rupture, there could be certain adverse impacts of a temporary nature; however, it is anticipated that there would be little long range impact on species and ecosystems from such an occurrence. The most significant impact of such an accident would be repair operations which could release sediments or debris to water bodies, create water demands for hydrostatic testing, possibly create a need for blasting, and other construction operations. Impacts may be increased because of the difficulty in scheduling repairs to meet the needs of fish or other wildlife species.1/
>
> The proposed route intersects several recognized major faults in the active seismic region south of 67 degrees N; however, risk of significant tectonic movement on these faults is essentially unknown at present. Many additional faults are also postulated in Zone 3 where this segment is characterized by the frequent occurrence of sizeable earthquakes that have yet to be identified with individual faults.2/
>
> The occurrence of large earthquakes is a potentially serious hazard to the integrity of the proposed pipeline. Seismic shaking or surface faulting accompanying a large shock could rupture the pipeline directly or cause failure in the foundation material that could lead to rupture. Furthermore, large earthquakes could trigger landslides that could jeopardize the integrity of the pipeline.2/

1/Applicant's Submission, Exhibit Z-1, Vol. 1, Sect. 3, pp. 3-19.
2/*Ibid.*, Sect. 2, pp. 2-76.

b. Analysis of Submission

The Applicant's Submission discusses some of the environmental damages that might result from natural catastrophes or man-caused gas pipeline accidents. Natural catastrophes could occur as a direct result of, or because of, some aggravation caused by the existence of the pipeline. They may also occur for reasons which have no connection with the existence of the pipeline. The former group includes land subsidence, frost bulbs (soil heaves), solifluction, and stream scour. The latter group includes earthquakes, floods, landslides, and forest fires.

Man-caused casualties include accidental fires, explosions, inadvertent collisions, and machinery failure, plus those from vandalism or sabotage. Most of these casualties result from improper judgements, careless workmanship, and ignorance, but the probability of deliberate vandalism or sabotage has not been dismissed by the Applicant.

Pipeline casualties have occurred due to many causes, but available statistical data show the most prevalent man-caused type of pipeline casualty in the contiguous 48 states has been due to inadvertent damage by outside parties. This type of accident should not occur with any significant frequency in the relatively isolated area of the Alcan pipeline route. Rupture of the Alcan pipe due to natural causes would lead to fire and/or explosion only if a source of ignition were present. A rupture caused during maintenance might result in explosion and fire; the use of spark proof tools wherever possible could reduce significantly the probability of accidental ignition where gas leakage is present. Due to the prevailing dry atmosphere, the possibility of static electricity as a source of ignition is high.

It is noted that the chance of a pipe rupture occurring is greater with a chilled pipeline made of the usual pipeline steel because of the greatly increased brittleness of the steel at low temperatures.

Gas turbines sometimes fail in a manner that could ignite combustible mixtures of gas and air. One such mode is an explosion in the combustor due to a failure to obtain proper ignition. A second mode is the fracture of either a compressor blade or turbine blade with resultant metal impacting at high velocities so as to create high temperatures. A third mode is the seizing of a bearing and the creation of high temperatures due to excessive friction. The temperature of the exhaust gases from a gas turbine (about 900°F) begins to approach the ignition temperature of a gas/air mixture. Shielding of the gas turbine to prevent hot flying metal from reaching gas-containing equipment and a high level of ventilation of the engine room should inhibit this type of casualty from affecting the integrity of the pipeline.

A buried pipeline may be assumed to move as the ground in which it is buried moves. In the event of an earthquake, the pipe would move with the earth. Calculations of seismic effects are usually made on that basis in order to estimate the maximum possible stresses that might be induced by a stated earth movement. Under actual conditions, it is probable that stresses in a buried line might be less than the theoretical values due to relative movement between the containment trench and the pipe. This would depend on the looseness of the fill, the height of the cover, and the bends in the pipe, both vertical and horizontal.

A rupture of the pipeline from whatever cause would release the gas contained therein. Because of the high internal pressure and the compressibility of the gas, the rate of energy release is great. Any object in the immediate path of the gas would receive a high pressure impact which would be similar to or greater than that caused by a hurricane or a tornado. Buildings could be demolished, trees broken off or uprooted, and movable objects including animals and people could be moved horizontally or blown over. Under special circumstances, loss of life could ensue. Vital damage area due to overpressure would not be large--a few hundred feet as a maximum. On the other hand, fire resulting from such a failure could have highly damaging effects due to the large volume of gas liberated (in the case of the proposed pipeline, as much as 20 miles of contained, high density gas between block valves could be liberated). If this amount of gas were ignited, the subsequent combustion could liberate energy equal to 35 million kilowatt hours. This large amount of energy, as heat, could melt the permafrost to a depth of one foot over an area of about 500 acres, assuming permafrost of 100% water content and a temperature of 10°F. It should not be concluded that this effect will actually occur; these figures are intended to emphasize the impressive magnitude of the energy potential of the massive volume of highly compressed gas, thereby underscoring the absolute necessity for meticulous system safety planning.

c. Conclusions

i. The Applicant's Submission describes some casualties that may occur to the gas pipeline, but minimizes the potential for resulting damage to the environment.

ii. The effects of fire and explosion, due to pipeline rupture, on the immediate environment is a variable of considerable magnitude depending on the nature of the rupture and the location, but the potential for serious environmental damage appears to be much greater than the Applicant has indicated.

iii. The Applicant has failed to describe in detail the safety devices, procedures, or techniques to be used to minimize the probability of a pipeline rupture and, if one should occur, how its effects would be mitigated.

iv. The Applicant has not described in detail what design factors would be applied to minimize pipeline stresses resulting from environmental influences, although the need to do so has been recognized with the statement that a detailed design, mile by mile, will be made prior to initiating construction.

v. Use of spark proof tools, protection against static electricity, and shielding gas turbines should mitigate the possibilities of ignition of leaking gas.

APPENDIX A. INVENTORY OF ALCAN PIPELINE CROSSING.

IROQUOIS RESEARCH INST.
WORKSHEET 1455 - 01

ALCAN PIPELINE CROSSING INVENTORY - PROJECT 1455

ITEM NO.	MILE POST	ALCAN ID	CROSSING NAME	CROSSING TYPE: STREAM	TRAIL	HAUL ROAD	HIGHWAY	HAINES	CANOL	ALYESKA	OTHER	REMARKS
1	19	A				x						
2	19	-									x	Gas Fuel Line
3	30-87	-	Sagavanirktok F.P.	x								About 40 crossings
4	62.4	1	Sagavanirktok River	x								
5	64.9	-			x							
6	69.1	2	Sagavanirktok River	x								
7	69.9	-			x							
8	74				x							
9	78				x							
10	79				x							
11	82				x							
12	90.5	A				x						
13	90.5	-								x		Discrepancy With APC-D9
14	92.4	-									x	Gas Fuel Line
15	98.2	-	Unnamed Creek	x								
16	100.2	3	Unnamed Creek	x								
17	103.3	4	Unnamed Creek	x								
18	105	-								x		Discrepancy With APC-D9
19	110	-			x							
20	110.5	-			x							
21	118	5	Unnamed Creek	x								
22	121	-			x							
23	122	-			x							
24	123	-			x							
25	125	6	Toolik River	x								
SPREAD TOTALS				Abt.47	11	2	0	0	0	2	2	

REF. DOC. ALCAN Z2 SPREAD NO. 1 PREPARED BY Jim Erlandson DATE Aug. 19, 1976 PAGE 1 OF 13 PAGES

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ALCAN PIPELINE CROSSING INVENTORY - PROJECT 1455

ITEM NO.	MILE POST	ALCAN ID	CROSSING NAME	CROSSING TYPE: STREAM	TRAIL	HAUL ROAD	HIGHWAY	HAINES	CANOL	ALYESKA	OTHER	REMARKS
26	127.5	7	Kuparuk River	x								
27	127.5	-								x		Discrepancy With APC-D9
28	127.5	A				x						
29	127.5	-									x	Gas Fuel Line
30	143.6	8	Atigun River	x								
31	144.7	-								x		
32	144.7	A				x						
33	144.7	-									x	Gas Fuel Line
34	146.4	-									x	Gas Fuel Line
35	146.4	-								x		
-	146.4	A				x						Text Indicates Crossing Not on Map
36	148.7	9	Unnamed Creek	x								
37	149.3	10	Atigun River	x								
38	150	10	Atigun River	x								
39	154.4	10	Atigun River	x								
40	155.4	11	Unnamed Creek	x								
41	156.2	12	Atigun River	x								
-	156.8	A				x						Text Indicates Crossing Not on Map
42	160.8	13	Unnamed Creek	x								
43	160.8	-								x		
44	160.8	A				x						
45	163.5	14	Atigun River	x								
46	166.1	-				x						
47	166.2	-				x						
48	168.5	-								x		
49	170.2	-				x						
50	170.2	-								x		
51	171.5	-				x						
52	174.2	15	NFK Chandler River	x								Text Indicates Dietrich R.
53	175.7	A				x						
54	176.8	16	Dietrich River Flood Plain								x	4.6 Miles
55	185.1	17	Deitrich River Flood Plain								x	13.1 Miles
56	198.8	18	Snowden Creek	x								
SPREAD TOTALS												

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ALCAN PIPELINE CROSSING INVENTORY - PROJECT 1455

ITEM NO.	MILE POST	ALCAN ID	CROSSING NAME	CROSSING TYPE: STREAM	TRAIL	HAUL ROAD	HIGHWAY	HAINES	CANOL	ALYESKA	OTHER	REMARKS
57	199.8	19	Dietrich River	x								
58	201	19	Dietrich River	x								
59	201.9	20	Unnamed Creek	x								
60	204.2	20	Unnamed Creek	x								
61	205.3	21	Dietrich River	x								
62	208.6	22	MFK Koyukuk River	x								
63	215.3	23	Linda Creek	x								
64	215.7	24	Gold Creek	x								
65	216.1	-			x							
66	216.6	25	Sheep Creek	x								
67	216.9	26	Wolf Pup Creek	x								
68	217.3	27	Nugget Creek	x								
69	218.8	28	Over Creek	x								
70	220	-	Rainbow Gulch Creek	x								
71	220.4	-	Coon Gulch Creek	x								
72	220.7	-	Bluff Gulch Creek	x								
73	221.9	29	MFK Koyukuk River	x								
74	222.2	30	Hammond River	x								
75	222.2	-									x	Winter Road
76	223.5	-									x	Winter Road
77	224.8	-									x	Winter Road
78	224.8	31	MFK Koyukuk River	x								
79	225.5	32	Minnie Creek	x								
SPREAD TOTALS				31	1	0	0	0	0	6	8	

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IROQUOIS RESEARCH INST.
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ALCAN PIPELINE CROSSING INVENTORY - PROJECT 1455

ITEM NO.	MILE POST	ALCAN ID	CROSSING NAME	CROSSING TYPE: STREAM	TRAIL	HAUL ROAD	HIGHWAY	HAINES	CANOL	ALYESKA	OTHER	REMARKS
80	227	-									x	Winter Road
81	230	-	Dry Gulch Creek	x								
82	230.8	-									x	Winter Road
83	231.5	-									x	Winter Road
84	233.5	33	Marion Creek	x								
85	234.7	-									x	Winter Road
86	235.1	-									x	Winter Road
87	235.1	-									x	Winter Road
88	236.4	34	Clara Creek	x								
89	237	-									x	Winter Road
90	237.8	35	Sltate Creek	x								
91	238.1	-									x	Winter Road
92	239.1	-			x							
93	240	-			x							
94	243.4	36	Rosie Creek	x								
95	246	A				x						
96	248	-	Unnamed Creek	x								
97	251.4	-									x	Winter Road
98	252.2	A				x						
99	253	-									x	Winter Road
100	256	-									x	Winter Road
101	256.7	37	SFK Koyukuk	x								
102	263.1	-									x	Winter Road
103	263.9	-									x	Winter Road
104	266.4	-									x	Winter Road
105	267.9	A				x						
106	267.9	-									x	Winter Road
107	268.6	38	Jim River	x								
108	270.8	39	Douglas Creek	x								
109	271.5	-									x	Winter Road
110	272.8	-									x	Winter Road
111	273	-									x	Winter Road
112	275.2	-								x		Pump Station
113	276.5	-									x	Winter Road
114	277.9	40	Prospect Creek	x								
	SPREAD TOTALS											

REF. DOC. ALCAN Z2 SPREAD NO. 3 PREPARED BY Jim Erlandson DATE 8/19/76 PAGE 4 OF 13 PAGES

IROQUOIS RESEARCH INST.
WORKSHEET 1455 - 01

ALCAN PIPELINE CROSSING INVENTORY - PROJECT 1455

ITEM NO.	MILE POST	ALCAN ID	CROSSING NAME	CROSSING TYPE: STREAM	TRAIL	HAUL ROAD	HIGHWAY	HAINES	CANOL	ALYESKA	OTHER	REMARKS
115	282.4	-	Unnamed Creek	x								
116	285	-			x							
117	285.3	-	NFK Bonanza Creek	x								
118	287.1	41	Bonanza Creek	x								
119	290.8	-	Unnamed Creek	x								
120	293.2	-			x							
121	295	-			x							
122	296.1	42	Fish Creek	x								
123	298	-	Fish Creek	x								
124	298.8	-	Fish Creek	x								
125	301.6	A				x						
126	304.1	43	Kanuti River	x								
127	304.2	-			x							
128	307.5	-	Unnamed Creek	x								
129	309.4	A				x						
130	309.9	-	Unnamed Creek	x								
131	310.4	-								x		Discrepancy With APC-D9
132	312.3	-								x		Discrepancy With APC-D9
133	316.2	-	Unnamed Creek	x								
134	318.5	-	Unnamed Creek	x								
135	325.7	-			x							
136	325.8	-	Unnamed Creek	x								
137	329.5	-			x							
138	329.5	44	Unnamed Creek	x								
139	330.3	-			x							
140	331.1	-			x							
141	332.3	-	Unnamed Creek	x								
142	332.8	-			x							
143	333.5	-	Unnamed Creek	x								
144	334	-			x							
145	335.8	-			x							
146	336	-	Unnamed Creek	x								
147	337.1	-			x							
148	338.5	-			x							
149	340.5	-	Unnamed Creek	x								
SPREAD TOTALS												

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ALCAN PIPELINE CROSSING INVENTORY - PROJECT 1455

ITEM NO.	MILE POST	ALCAN ID	CROSSING NAME	CROSSING TYPE: STREAM	TRAIL	HAUL ROAD	HIGHWAY	HAINES	CANOL	ALYESKA	OTHER	REMARKS
150	340.6	A				x						
151	341.3	-	Unnamed Creek	x								
152	346.6	-	Unnamed Creek	x								
153	347.6	-	Unnamed Creek	x								
154	347.6	A				x						
155	349.9	-	Unnamed Creek	x								
156	351	-	Unnamed Creek	x								
SPREAD TOTALS				33	15	7	0	0	0	3	19	

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ITEM NO.	MILE POST	ALCAN ID	CROSSING NAME	CROSSING TYPE: STREAM	TRAIL	HAUL ROAD	HIGHWAY	HAINES	CANOL	ALYESKA	OTHER	REMARKS
157	352.6	45	Yukon River	x								
158	353.9	A				x						
159	362.6	46	Isom Creek	x								
160	366.8	A				x						
161	366.8	-								x		
162	366.9	-	Elliot Highway				x					
163	367.5	-	Elliot Highway				x					
164	367.6	-	Unnamed Creek	x								
165	370	-	Unnamed Creek	x								
166	372.4	-	Elliot Highway				x					
167	372.5	-	Unnamed Creek	x								
168	373.8	-	Elliot Highway				x					
169	374.5	-	Elliot Highway				x					
170	376.4	-	Elliot Highway				x					
171	377.9	47	Hess Creek	x								
	378.6	-								x		Discrepancy With APC-D9
	378.9	-								x		Discrepancy With APD-D9
172	383.7	-	Erickson Creek	x								
173	384	48	Erickson Creek	x								
174	386.7	-	Unnamed Creek	x								
175	391.1	49	Lost Creek	x								
176	393.7	A	Elliot Highway				x					
177	393.7	A				x						
178	396	A				x						
179	397.5	50	Tolovana River	x								
180	397.5	-									x	Tractor Trail
181	397.6	-									x	Tractor Trail
182	399	-	Shorty Creek	x								
183	405	-	Wilber Creek	x								
184	407.9	51	Slate Creek	x								
185	412.1	52	Tatalina River	x								
186	414.5	-	Unnamed Creek	x								
187	416.7	53	Globe Creek	x								
188	419.4	-	Unnamed Creek	x								
189	420.8	-	Unnamed Creek	x								
SPREAD TOTALS												

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IROQUOIS RESEARCH INST.
WORKSHEET 1455 - 01

ALCAN PIPELINE CROSSING INVENTORY - PROJECT 1455

ITEM NO.	MILE POST	ALCAN ID	CROSSING NAME	CROSSING TYPE: STREAM	TRAIL	HAUL ROAD	HIGHWAY	HAINES	CANOL	ALYESKA	OTHER	REMARKS
190	422.9	54	Aggie Creek	x								
191	423.7	-	Unnamed Creek	x								
192	424	-			x							
193	430.7	55	Washington Creek	x								
194	433.7	-	Unnamed Creek	x								
195	436	-	Unnamed Creek	x								
196	436.7	56	Chatanika River	x								
197	440.8	57	Treasure Creek	x								
198	443	-	Murphy Dome Road				x					
199	443.5	-			x							
200	446.7	58	Gold Creek Stream	x								
201	447.3	A				x						
202	449.6	59	Engineer Creek	x								
203	450.3	-			x							
204	452.5	-			x							
205	453.1	A	Chena Hot Springs Rd.				x					
206	454.7	-			x							
207	456.9	-	Steele Creek	x								
208	457.5	60	Chena River	x								
209	458.3	A	Nordale Road								x	Road
210	460.1	-	Unnamed Creek	x								
211	460.6	A	Peede Road								x	Road
212	464.4	A	Plack Road								x	Road
213	466.5	-	Unnamed Creek	x								
214	468.5	A									x	Road
215	468.8	A									x	Road
216	468.9	61	Moose Creek	x								
-	469.9	-								x		Discrepancy With APC-D9
SPREAD TOTALS				33	5	5	9	0	0	4	7	

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IROQUOIS RESEARCH INST.
WORKSHEET 1455 - 01

ALCAN PIPELINE CROSSING INVENTORY - PROJECT 1455

ITEM NO.	MILE POST	ALCAN ID	CROSSING NAME	CROSSING TYPE: STREAM	TRAIL	HAUL ROAD	HIGHWAY	HAINES	CANOL	ALYESKA	OTHER	REMARKS
217	471	-	Unnamed Creek	x								
218	472.3	A									x	Road
219	472.6	62	French Creek	x								
220	474.1	A									x	Road
221	474.2	63	French Creek	x								
222	476.5	63	French Creek	x								
223	477.1	A									x	Road
224	481.6	63	French Creek	x								
225	483.5	-	Unnamed Creek	x								
226	485.9	-	Unnamed Creek	x								
227	486.9	A									x	Road
228	488.4	64	Little Salcha River	x								
229	489.6	-	Unnamed Creek	x								
230	493.3	65	Salcha River	x								
231	495.2	-			x							
232	497.1	66	Redmond Creek	x								
233	502.5	-	Unnamed Creek	x								
234	503.8	67	Gold Run Creek	x								
235	506.1	-	Unnamed Creek	x								
236	517.7	68	Shaw Creek	x								
237	523.5	-									x	Road
-	526.4	-								x		Discrepancy With APC-D9
-	527.	-								x		Discrepancy With APC-D9
238	526.7	A	Richardson Highway				x					
239	528.8	69	Tanana River	x								
240	529.5	A	Richardson Highway				x					
241	529.5	-								x		
242	537.5	-	Jack Warren Road								x	Road
243	538	-			x							
244	538.8	-									x	Road
245	539	-									x	Road
246	545.7	-									x	Road
247	549	-	Unnamed Creek	x								
248	549.8	-	Granite Creek	x								
249	551.7	-	Rhodes Creek	x								
	SPREAD TOTALS											

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ALCAN PIPELINE CROSSING INVENTORY - PROJECT 1455

ITEM NO.	MILE POST	ALCAN ID	CROSSING NAME	CROSSING TYPE: STREAM	TRAIL	HAUL ROAD	HIGHWAY	HAINES	CANOL	ALYESKA	OTHER	REMARKS
250	555.2	69a	Sawmill Creek	x								
251	566	70	Gerstle River	x								
252	566	-							x			
253	566	-							x			
254	567	-									x	Road
255	568.5	-	Unnamed Creek	x								
256	570.2	71	Little Gerstle River	x								
257	572.4	A	Alaska Highway				x					
258	572.4	-						x				
259	572.4	-							x			
260	574.7	-			x							
261	576	-			x							
262	578	72	Johnson River	x								
263	578	-						x				
264	578	-						x				
265	580.3	-	Dry Creek	x								
266	583.5	-									x	Peat Bog
267	584.1	-						x				
268	584.1	73	Sears Creek	x								
269	584.1	-						x				
270	585.8	-	Unnamed Creek	x								
271	586	-						x				
272	587.1	-						x				
273	587.2	-	Berry Creek	x								
274	588.3	-						x				
275	588.4	-						x				
276	589.8	-	Unnamed Creek	x								
277	592.5	-	Sam Creek	x								
278	594.1	-						x				
279	594.5	-	Unnamed Creek	x								
280	596	-	Unnamed Creek	x								
281	596.6	-			x							
282	596.8	A	Alaska Highway				x					
283	596.8	-							x			
284	598	-						x				
285	599.2	75	Chief Creek	x								
SPREAD TOTALS				33	5	0	4	11	4	1	11	

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IROQUOIS RESEARCH INST.
WORKSHEET 1455 - 01

ALCAN PIPELINE CROSSING INVENTORY - PROJECT 1455

ITEM NO.	MILE POST	ALCAN ID	CROSSING NAME	CROSSING TYPE								REMARKS
				STREAM	TRAIL	HAUL ROAD	HIGHWAY	HAINES	CANOL	ALYESKA	OTHER	
286	600.6	76	Bear Creek	x								
287	603.5	-									x	Peat Bog
288	608.2	A					x					
289	608.2	-						x				
290	608.2	-							x			
291	609.9	-						x				
292	610	77	Robertson River	x								
293	610.1	--						x				
294	613.3	-	Unnamed Creek	x								
295	615.3	-	Sheep Creek	x								
296	616.5	-	Unnamed Creek	x								
297	616.8	-						x				
298	617.5	-	Unnamed Creek	x								
299	618	-						x				
300	618.9	-	Unnamed Creek	x								
301	619.5	-	Unnamed Creek	x								
302	623.4	77a	Yerric Creek	x								
303	625.6	-									x	Peat Bog
304	626.2	A	Alaska Highway				x'					
305	626.2	-							x			
306	626.2	-						x				
307	630	-									x	Peat Bog (2 Miles)
308	631.5	-							x			
309	631.5	-			x							
310	631.6	-							x			
311	633	-	Land Plane Road								x	Road
312	636.6	-									x	Road
313	636.6	-									x	Road
314	636.7	-									x	Road
315	643.7	-									x	Road
316	646.5	78	Creek	x								
317	648.6	79	Tok River	x								
318	652.5	-									x	Overflow Channel
319	654.7	80	Tanana River	x								
320	656.6	-	Taylor Highway				x					
SPREAD TOTALS												

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IROQUOIS RESEARCH INST.
WORKSHEET 1455 - 01

ALCAN PIPELINE CROSSING INVENTORY - PROJECT 1455

ITEM NO.	MILE POST	ALCAN ID	CROSSING NAME	CROSSING TYPE: STREAM	TRAIL	HAUL ROAD	HIGHWAY	HAINES	CANOL	ALYESKA	OTHER	REMARKS
321	664.1	-						x				
322	665	-						x				
323	665	-							x			
324	665.4	-						x				
325	665.4	-							x			
326	666.9	-						x				
327	668.4	A	Alaska Highway				x					
328	668.4	-						x				
329	668.4	-							x			
330	672.3	A	Alaska Highway				x					
331	672.3	-							x			
332	672.3	-						x				
333	675.7	81	Bitters Creek	x								
334	676.4	-									x	Road
335	679.8	-						x				
336	681.3	-						x				
337	681.4	-						x				
338	681.5	-						x				
339	681.5	-	Unnamed Creek	x								
340	682.5	-	Unnamed Creek	x								
341	684.5	A	Alaska Highway				x					
342	684.7	-	Unnamed Creek	x								
343	685.1	A	Alaska Highway				x					
344	685.1	-						x				
345	686	-						x				
346	687.2	82	Beaver Creek	x								
347	688	-			x							
348	688.7	-	Unnamed Creek	x								
349	693.3	-						x				
350	693.4	A	Alaska Highway				x					
351	693.4	-							x			
352	694.7	83	Silver Creek	x								
353	695.9	-						x				
354	696.8	-						x				
355	698.2	-						x				
SPREAD TOTALS												

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ALCAN PIPELINE CROSSING INVENTORY - PROJECT 1455

ITEM NO.	MILE POST	ALCAN ID	CROSSING NAME	CROSSING TYPE								REMARKS
				STREAM	TRAIL	HAUL ROAD	HIGHWAY	HAINES	CANOL	ALYESKA	OTHER	
356	698.5	-						x				
357	700.4	84	Ten Mile Creek	x								
358	703.5	-						x				
359	703.6	-			x							
360	705.1	-						x				
361	706.6	85	Gardiner Creek	x								
362	716.3	-	Unnamed Creek	x								
363	717.7	-	Unnamed Creek	x								
364	717.8	A	Alaska Highway				x					
365	717.8	-						x				
366	717.8	-							x			
367	718.2	-	Unnamed Creek	x								
368	719.1	-						x				
369	721.2	-	Unnamed Creek	x								
370	725.9	86	Desper Creek	x								
371	727.8	87	Scottie Creek	x								
372	728.6	A	Alaska Highway				x					
373	728.6	-							x			
SPREAD TOTALS				27	3	0	10	27	11	0	10	

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IROQUOIS RESEARCH INST.
WORKSHEET 1455-01

ALCAN PIPELINE CROSSING INVENTORY - TOTALS - PROJECT 1455

SPREAD NUMBER	CROSSING TYPE							
	STREAM	TRAIL	HAUL ROAD	HIGHWAY	HAINES	CANOL	ALYESKA	OTHER
SPREAD 1	Abt. 47	11	2	0	0	0	2	2
SPREAD 2	31	1	10	0	0	0	6	8
SPREAD 3	33	15	7	0	0	0	3	19
SPREAD 4	33	5	5	9	0	0	4	7
SPREAD 5	33	5	0	4	11	4	3	11
SPREAD 6	27	3	0	10	27	11	0	10
TOTALS	204	42	24	23	39	15	18	57

REF. DOC. ALCAN Z2 PREPARED BY JIM ERLANDSON DATE AUGUST 19, 1976

APPENDIX B. INVENTORY OF SOIL CHARACTERISTICS AT ALCAN PIPELINE CROSSINGS.

IROQUOIS RESEARCH INST
WORKSHEET 1455- 02

ALCAN PIPELINE CROSSING INFORMATION INVENTORY- PROJECT 1455

ITEM NO	MILE POST	CROSSING TYPE	SOIL				TERRAIN				SLOPE				PERMAFROST				
			ORGANIC	SILT	SAND	GRAVEL	FLOOD PLAIN	TERRACE	MOUNT	OTHER	STEEP	MOD.	GENTLE	NONE	NONE	ICE RICH	ICE POOR	DISCON-TINUOUS	OTHER
1	19	Road	x	M	x	x		x						x		x			wedges & masses
2	19	GFL	x	M	x	x		x						x		x			wedges & masses
3	30-87	Stream		M	x	x	x							x		x			ice wedges
4	62.4	Stream		M	x	x	x							x	x				thaw bulb
5	64.9	Trail		M	x	x	x							x		x			wedges & masses
6	69.1	Stream		M	x	x	x							x	x				thaw bulb
7	69.9	Trail		M	x	x	x							x		x			wedges & masses
8	74	Trail	x	x	x	U		x					x			x			wedges & masses
9	78	Trail	x	x	x	U		x					x			x			wedges & masses
10	79	Trail	x	x	x	U		x					x			x			wedges & masses
11	82	Trail	x	x	x	U		x					x			x			wedges & masses
12	90.5	Road	S	M	x	x		x				x				x			wedges & masses
13	90.5	Alyeska	S	M	x	x		x				x				x			wedges & masses
14	92.4	GFL	S	M	x	x		x				x				x			ice wedges
15	98.2	Stream	S	M	x	x		x					x			x			ice wedges
16	100.2	Stream	S	M	x	x		x					x			x			ice wedges
17	103.3	Stream	S	M	x	x		x					x			x			ice wedges
18	105	Alyesk	S	M	x	x		x					x			x			ice wedges
19	110	Trail	S	M	x	x		x					x			x			ice wedges
20	110.5	Trail	S	M	x	x		x					x			x			ice wedges
21	118	Stream	M	M	x	x			x			x				x			Moraine
22	121	Trail	x	x	S			x					x			x			ice wedges
23	122	Trail	x	x	S			x					x			x			ice wedges
24	123	Trail	x	x	S			x					x			x			ice wedges
25	125	Stream	M	M	x	x	x						x			x			ice wedges
SPREAD TOTALS			20	25	25	22	6	18	1	0	0	4	14	7	2	23	0	0	25

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IROQUOIS RESEARCH INSTITUTE
WORKSHEET 1455- 02

ALCAN PIPELINE CROSSING INFORMATION INVENTORY- PROJECT 1455

ITEM NO	MILE POST	CROSSING TYPE	SOIL: ORGANIC	SOIL: SILT	SOIL: SAND	SOIL: GRAVEL	TERRAIN: FLOOD PLAIN	TERRAIN: TERRACE	TERRAIN: MOUNT	TERRAIN: OTHER	SLOPE: STEEP	SLOPE: MOD.	SLOPE: GENTLE	SLOPE: NONE	PERMAFROST: NONE	PERMAFROST: ICE RICH	PERMAFROST: ICE POOR	PERMAFROST: DISCON-TINUOUS	PERMAFROST: OTHER
26	127.5	Stream		x	x	x	x						x			x			ice wedges
27	127.5	Alyeska		x	x	x	x						x			x			ice wedges
28	127.5	Road		x	x	x	x						x			x			ice wedges
29	127.5	GFL		x	x	x	x						x			x			ice wedges
30	143.6	Stream	S	x	x		x						x			x			wedges & lenses
31	144.7	Alyeska	S	x	x		x						x			x			wedges & lenses
32	144.7	Road	S	x	x		x						x			x			wedges & lenses
33	144.7	GFL	S	x	x		x						x			x			wedges & lenses
34	146.4	GFL		x	x	x		x					x			x			wedges & lenses
35	146.4	Alyeska		x	x	x		x					x			x			wedges & lenses
--	146.4	Road		x	x	x		x					x			x			wedges & lenses
36	148.7	Stream		M	x	x	x						x			x			
37	149.3	Stream		M	x	x	x						x		x				thaw bulb
38	150	Stream		M	x	x	x						x		x				thaw bulb
39	154.4	Stream		M	x	x	x						x		x				thaw bulb
40	155.4	Stream		M	x	x	x						x			x			
41	156.2	Stream		M	x	x	x						x		x				thaw bulb
--	156.8	Road		M	x	x	x						x			x			
42	160.8	Stream		M	x	x			x			x				x			
43	160.8	Alyeska		M	x	x			x			x				x			
44	160.8	Road		M	x	x			x			x				x			
45	163.5	Stream		M	x	x			x			x			x				thaw bulb
46	166.1	Road				x			x		x					x			
47	166.2	Road				x			x		x					x			
48	168.5	Alyeska				x			x		x					x			
49	170.2	Road			x	x			x		x					x			
50	170.2	Alyeska			x	x			x		x					x			
51	171.5	Road			x	x			x		x					x			
52	174.2	Stream			x	x				Fan		x				x			
53	175.7	Road		x	x	x		x				x					x		
54	176.8	Flood Pl.		S	x		x						x			x			
55	185.1	Flood Pl.		S	x		x						x			x			
56	198.8	Stream		x	x	x	x						x			x			
57	199.8	Stream		x	x	x	x						x		x				thaw bulb
58	201	Stream		x	x	x	x						x		x				thaw bulb
59	201.9	Stream		x	x	x	x						x		x				thaw bulb
60	204.3	Stream		x	x	x	x						x		x				thaw bulb
SPREAD TOTALS																			

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IROQUOIS RESEARCH INSTITUTE
WORKSHEET 1455- 02

ALCAN PIPELINE CROSSING INFORMATION INVENTORY- PROJECT 1455

ITEM NO	MILE POST	CROSSING TYPE	SOIL: ORGANIC	SOIL: SILT	SOIL: SAND	SOIL: GRAVEL	TERRAIN: FLOOD PLAIN	TERRAIN: TERRACE	TERRAIN: MOUNT	TERRAIN: OTHER	SLOPE: STEEP	SLOPE: MOD.	SLOPE: GENTLE	SLOPE: NONE	PERMAFROST: NONE	PERMAFROST: ICE RICH	PERMAFROST: ICE POOR	PERMAFROST: DISCON-TINUOUS	PERMAFROST: OTHER
61	205.3	Stream		x	x	x	x						x		x				thaw bulb
62	208.6	Stream		x	x	x	x						x		x				thaw bulb
63	215.3	Stream		x	x	x				Fan		x			x				thaw bulb
64	215.7	Stream		x	x	x				Fan		x			x				thaw bulb
65	216.1	Trail		M	x	x		x					x				x		
66	216.6	Stream		x	x	x				Fan		x			x				thaw bulb
67	216.9	Stream		x	x	x				Fan		x			x				thaw bulb
68	217.3	Stream		x	x	x				Fan		x			x				thaw bulb
69	218.8	Stream		x	x	x				Fan		x			x				thaw bulb
70	220	Stream		x	x	x				Fan		x			x				thaw bulb
71	220.4	Stream		x	x	x				Fan		x			x				thaw bulb
72	220.7	Stream		x	x	x				Fan		x			x				thaw bulb
73	221.9	Stream		x	x	x	x						x		x				thaw bulb
74	222.2	Stream		x	x	x				Fan		x			x				thaw bulb
75	222.2	Road		M	x	x		x					x				x		
76	223.5	Road		M	x	x		x					x				x		
77	224.8	Road		M	x	x		x					x				x		
78	224.8	Stream		x	x	x	x						x				x		thaw bulb
79	225.5	Stream		x	x	x				Fan		x			x				thaw bulb
SPREAD TOTALS			4	49	53	50	26	8	10	12	6	17	33	0	24	27	5	0	35

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IROQUOIS RESEARCH INSTITUTE
WORKSHEET 1455- 02

ALCAN PIPELINE CROSSING INFORMATION INVENTORY- PROJECT 1455

ITEM NO	MILE POST	CROSSING TYPE	SOIL				TERRAIN				SLOPE				PERMAFROST				
			ORGANIC	SILT	SAND	GRAVEL	FLOOD PLAIN	TERRACE	MOUNT	OTHER	STEEP	MOD.	GENTLE	NONE	NONE	ICE RICH	ICE POOR	DISCON-TINUOUS	OTHER
80	227	Road		x	x	x		x					x				x		
81	230	Stream		x	x	x				Fan			x		x				thaw bulb
82	230.8	Road		x	x	x		x									x		
83	231.5	Road		x	x	x		x					x				x		
84	233.5	Stream		x	x	x				Fan			x		x				thaw bulb
85	234.7	Road		x	x	x		x					x				x		
85	235.1	Road		x	x	x		x					x				x		
86	235.1	Road		x	x	x		x					x				x		
87	235.1	Road		x	x	x		x					x				x		
88	236.4	Stream		x	x	x				Fan			x						
89	237	Road		x	x	x		x					x				x		
90	237.8	Stream		x	x	x				Fan			x		x				thaw bulb
91	238.1	Road		x	x	x		x					x				x		
92	239.1	Trail		x	x	x		x					x				x		
93	240	Trail		x	x	x		x					x				x		
94	243.4	Stream		x	x	x				Fan		x			x				thaw bulb
95	246	Road		M	x	x		x					x			x			wedges & lenses
96	248	Stream		M	x	x		x					x			x			" " "
97	251.4	Road		M	x	x		x					x			x			" " "
98	252.2	Road		M	x	x		x					x			x			
99	253	Road		M	x	x		x					x			x			
100	256	Road		M	x	x		x					x			x			
101	256.7	Stream		x	x	x	x						x		x				thaw bulb
102	263.1	Road		x	x	x			x			x				x			masses & wedges
103	263.9	Road		x	x	x			x			x				x			" " "
104	266.4	Road		x	x	x			x			x				x			" " "
105	267.9	Road		x	x	x			x			x				x			" " "
106	267.9	Road		x	x	x			x			x				x			" " "
107	268.6	Stream		x	x	x				Fan			x		x				thaw bulb
108	270.8	Stream		x	x	x				Fan			x		x				" "
109	271.5	Road		x	x	x			x			x				x			
110	272.8	Road		x	x	x			x			x				x			
111	273	Road		x	x	x			x			x				x			
112	275.2	Alyeska		x	x	x			x			x				x			
113	276.5	Road		x	x	x			x			x					x		
114	277.9	Stream		x	x	x				Fan			x		x				thaw bulb
115	282.4	Stream		x	x	x				Fan			x		x				thaw bulb
116	285	Trail		x	x	x			x			x					x		
SPREAD TOTALS																			

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IROQUOIS RESEARCH INSTITUTE
WORKSHEET 1455- 02

ALCAN PIPELINE CROSSING INFORMATION INVENTORY- PROJECT 1455

ITEM NO	MILE POST	CROSSING TYPE	SOIL ORGANIC	SOIL SILT	SOIL SAND	SOIL GRAVEL	TERRAIN FLOOD PLAIN	TERRAIN TERRACE	TERRAIN MOUNT	TERRAIN OTHER	SLOPE STEEP	SLOPE MOD.	SLOPE GENTLE	SLOPE NONE	PERMAFROST NONE	PERMAFROST ICE RICH	PERMAFROST ICE POOR	PERMAFROST DISCON-TINUOUS	PERMAFROST OTHER
117	285.3	Stream		x	x	x				Fan			x		x				thaw bulb
118	287.1	Stream		x	x	x	x						x		x				" "
119	290.8	Stream		x	x	x				Fan			x		x				" "
120	293.2	Trail		x	x	x				Hills		x					x		
121	295	Trail		x	x	x				Hills		x					x		thaw bulb
122	296.1	Stream		x	x	x				Fan			x		x				" "
123	298	Stream		x	x	x				Fan		x			x				" "
124	298.8	Stream		x	x	x				Fan		x			x				" "
125	301.6	Road		x	x	x				Hills		x					x		
126	304.1	Stream		x	x	x	x						x		x				thaw bulb
127	304.2	Trail		x	x	x				Hills		x					x		
128	307.5	Stream		x	x	x				Fan			x		x				thaw bulb
129	309.4	Road		x	x	x				Hills		x					x		
130	309.9	Stream		x	x	x				Fan			x		x				" "
131	310.4	Alyeska		x	x	x				Hills		x					x		
132	312.3	Alyeska		x	x	x				Hills			x				x		
133	316.2	Stream		x	x	x				Fan			x		x				thaw bulb
134	318.5	Stream		x	x	x				Fan		x			x				" "
135	325.7	Trail		x	x	x				Hills		x					x		
136	325.8	Stream		x	x	x				Fan			x		x				" "
137	329.5	Trail		x	x	x				Hills		x					x		
138	329.5	Stream		x	x	x		x				x			x				" "
139	330.3	Trail		x	x	x				Hills							x		
140	331.1	Trail		x	x	x				Hills		x					x		
141	332.3	Stream		x	x	x				Hills			x		x				" "
142	332.8	Trail		x	x	x				Hills			x				x		
143	333.5	Stream		x	x	x				Hills			x		x				" "
144	334	Trail		x	x	x				Hills							x		
145	335.8	Trail		x	x	x				Hills							x		
146	336	Stream		x	x	x		x					x			x			
147	337.1	Trail		x	x	x				Hills		x					x		
148	338.5	Trail		x	x	x				Hills		x					x		
149	340.5	Stream		x	x	x				Fan			x			x			
150	340.6	Road		x	x	x				Hills		x					x		
151	341.3	Stream		x	S	S		x					x				x		lenses & masses
152	346.6	Stream		x	S	S		x					x				x		" " "
SPREAD TOTALS																			

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ALCAN PIPELINE CROSSING INFORMATION INVENTORY- PROJECT 1455

ITEM NO	MILE POST	CROSSING TYPE	SOIL				TERRAIN				SLOPE				PERMAFROST				
			ORGANIC	SILT	SAND	GRAVEL	FLOOD PLAIN	TERRACE	MOUNT	OTHER	STEEP	MOD.	GENTLE	NONE	NONE	ICE RICH	ICE POOR	DISCONTINUOUS	OTHER
153	347.6	Stream		x	S	S		x					x				x		lenses & masses
154	347.6	Road		x	S	S		x					x				x		" " "
155	349.9	Stream		x	S	S		x					x				x		" " "
156	351	Stream		x	S	S		x					x				x		" " "
SPREAD TOTALS			0	77	77	77	3	24	11	39	0	28	45	0	24	17	34	0	39

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IROQUOIS RESEARCH INSTITUTE
WORKSHEET 1455- 02

ALCAN PIPELINE CROSSING INFORMATION INVENTORY- PROJECT 1455

ITEM NO	MILE POST	CROSSING TYPE	SOIL: ORGANIC	SOIL: SILT	SOIL: SAND	SOIL: GRAVEL	TERRAIN: FLOOD PLAIN	TERRAIN: TERRACE	TERRAIN: MOUNT	TERRAIN: OTHER	SLOPE: STEEP	SLOPE: MOD.	SLOPE: GENTLE	SLOPE: NONE	PERMAFROST: NONE	PERMAFROST: ICE RICH	PERMAFROST: ICE POOR	PERMAFROST: DISCONTINUOUS	OTHER
157	352.6	Stream		x			x								x				thaw bulb
158	353.9	Road		x				x				x				x			
159	362.6	Stream		x	x	x				Hills			x			x			
160	366.8	Road		x	M	M				Hills		x					x		
161	366.8	Alyeska		x	M	M				Hills		x					x		
162	366.9	Highway		x	M	M				Hills		x					x		
163	367.5	Highway		x	M	M				Hills		x					x		
164	367.6	Stream		x	x	x				Fan			x			x			
165	370	Stream		x	x	x				Fan			x			x			
166	372.4	Highway		x	M	M				Hills		x				x			
167	372.5	Stream		x	x	x				Fan			x			x			
168	373.8	Highway		x	M	M				Hills		x				x			
169	374.5	Highway		x	M	M				Hills		x					x		
170	376.4	Highway		x	M	M				Hills		x					x		
171	377.9	Stream		x	x	x	x						x		x				thaw bulb
--	378.6	Alyeska		x	x	x	x						x		x				" "
--	378.9	Alyeska		x	x	x	x						x		x				" "
172	383.7	Stream		x	x	x	x						x		x				" "
173	384	Stream		x	x	x		x					x			x			
174	386.7	Stream		x	x	x				Fan			x			x			
175	391.1	Stream		x	x	x	x						x		x				" "
176	393.7	Highway		x	x	x				Hills		x					x		
177	393.7	Road		x	x	x				Hills		x					x		
178	396	Road		x	x	x				Hills		x					x		
179	397.5	Stream		x	x	x	x						x		x				" "
180	397.5	Trail		x	x	x	x						x			x			
181	397.6	Trail		x	x	x	x						x			x			
182	399	Stream		x	x	x		x					x			x			
183	405	Stream		x	x	x				Fan			x			x			
184	407.9	Stream		x	x	x				Fan			x			x			
185	412.1	Stream		x	x	x	x						x		x				thaw bulb
186	414.5	Stream		x	x	x				Fan			x			x			
187	416.7	Stream		x	x	x	x						x		x				thaw bulb
188	419.4	Stream		x	x	x				Fan			x			x			
189	420.8	Stream		x	x	x				Fan			x			x			
SPREAD TOTALS																			

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IROQUOIS RESEARCH INSTITUTE
WORKSHEET 1455- 02

ALCAN PIPELINE CROSSING INFORMATION INVENTORY- PROJECT 1455

ITEM NO	MILE POST	CROSSING TYPE	SOIL: ORGANIC	SOIL: SILT	SOIL: SAND	SOIL: GRAVEL	TERRAIN: FLOOD PLAIN	TERRAIN: TERRACE	TERRAIN: MOUNT	TERRAIN: OTHER	SLOPE: STEEP	SLOPE: MOD.	SLOPE: GENTLE	SLOPE: NONE	PERMAFROST: NONE	PERMAFROST: ICE RICH	PERMAFROST: ICE POOR	PERMAFROST: DISCON-TINUOUS	PERMAFROST: OTHER
190	422.9	Stream		x	x	x				Fan			x					x	lenses & masses
191	423.7	Stream		x	x	x				Fan			x					x	" " "
192	424	Trail		x	S	S				Hills		x					x		" " "
193	430.7	Stream		x	x	x	x						x		x				thaw bulb
194	433.7	Stream		x	x	x				Fan			x			x			
195	436	Stream		x	x	U	x							x				x	lenses & masses
196	436.7	Stream		x	x	U	x							x				x	" " "
197	440.8	Stream		x	x	x				Fan			x					x	" " "
198	443	Highway		x		x			x			x			x				
199	443.5	Trail		x	x	x			x			x			x				
200	446.7	Stream		x	x	x	x						x					x	
201	447.3	Road		x	x	x				Hills		x						x	
202	449.6	Stream		x	x	x				Hills		x						x	
203	450.3	Trail		x	x	x				Hills		x					x		
204	452.5	Trail		x	x	x				Hills		x					x		
205	453.1	Highway		x	x					Hills		x					x		
206	454.7	Trail		x	x		x						x			x			
207	456.9	Stream		x	x	x	x						x					x	
208	457.5	Stream		x	x		x						x		x				thaw bulb
209	458.3	Road		x	x		x						x			x			
210	460.1	Stream		x	x		x						x			x			
211	460.6	Road		x	x		x						x			x			
212	464.4	Road		x	x		x						x				x		
213	466.5	Stream		x	x		x						x				x		
214	468.5	Road		x	x		x						x				x		
215	468.8	Road		x	x	x	x						x				x		thaw bulb
216	468.9	Stream		x	x		x						x		x				
--	469.9	Alyeska		x	x		x						x		x				
SPREAD TOTALS			0	63	60	49	26	3	2	31	0	20	41	2	15	22	17	9	18

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IROQUOIS RESEARCH INSTITUTE
WORKSHEET 1455- 02

ALCAN PIPELINE CROSSING INFORMATION INVENTORY- PROJECT 1455

ITEM NO	MILE POST	CROSSING TYPE	SOIL ORGANIC	SOIL SILT	SOIL SAND	SOIL GRAVEL	TERRAIN FLOOD PLAIN	TERRAIN TERRACE	TERRAIN MOUNT	TERRAIN OTHER	SLOPE STEEP	SLOPE MOD.	SLOPE GENTLE	SLOPE NONE	PERMAFROST NONE	PERMAFROST ICE RICH	PERMAFROST ICE POOR	PERMAFROST DISCON-TINUOUS	PERMAFROST OTHER
217	471	Stream		x	x	U	x						x			x			
218	472.3	Road		x	x		x						x			x			
219	472.6	Stream		x	x	U	x						x			x			
220	474.1	Road		x	x		x						x			x			
221	474.2	Stream		x	x	U	x						x			x			
222	476.5	Stream		x	x	U	x						x			x			
223	477.1	Road		x	x			x					x			x			
224	481.6	Stream		x		U		x					x			x			
225	483.5	Stream		x		U		x					x			x			
226	485.9	Stream		x		U				Hills			x			x			
227	486.9	Road		x						Hills		x				x			lenses & masses
228	488.4	Stream		x	x	x	x						x			x			
229	489.6	Stream		x	x	x				Fan			x			x			
230	493.3	Stream		x	x	x	x						x			x			
231	495.2	Trail		x	x	x	x						x		x				thaw bulb
232	497.1	Stream		x	x	x	x						x			x			
233	502.5	Stream		x	x	x				Fan			x			x			
234	503.8	Stream		x	x	x				Fan			x			x			
235	506.1	Stream		x	x	x				Fan			x			x			
236	517.7	Stream	x	x	x	U	x							x				x	
237	523.5	Road	x	x	x	U	x							x				x	
--	526.4	Alyeska	x	x	x	U	x							x				x	
--	527	Alyeska	x	x	x	U	x							x				x	
238	526.7	Highway	x	x	x	U	x							x				x	
239	528.8	Stream		x	x	U	x							x	x				thaw bulb
240	529.5	Highway		x	x	U	x							x				x	
241	529.5	Alyeska		x	x	U	x							x				x	
242	537.5	Road		x	x	U	x							x				x	
243	538	Trail	x	x	x	U	x							x				x	
244	538.8	Road	x	x	x	U	x							x				x	
245	539	Road		x	x			x					x					x	
246	545.7	Road		S	S	x		x					x					x	
247	549	Stream		M	M	x		x					x					x	
248	549.8	Stream		M	M	x		x					x					x	
249	551.7	Stream		M	M	x		x					x					x	
250	555.2	Stream		M	M	x		x					x					x	
251	566	Stream		x	x	x	x							x	x				
SPREAD TOTALS																			

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ALCAN PIPELINE CROSSING INFORMATION INVENTORY- PROJECT 1455

ITEM NO	MILE POST	CROSSING TYPE	SOIL				TERRAIN				SLOPE				PERMAFROST				
			ORGANIC	SILT	SAND	GRAVEL	FLOOD PLAIN	TERRACE	MOUNT	OTHER	STEEP	MOD.	GENTLE	NONE	NONE	ICE RICH	ICE POOR	DISCON-TINUOUS	OTHER
252	566	Canol		M	M	x	x							x				x	
253	566	Canol		M	M	x	x							x				x	
254	567	Road		M	x	x		x					x					x	
255	568.5	Stream		M	x	x		x					x					x	
256	570.2	Stream		M	x	x		x					x					x	
257	572.4	Highway			x	x		x					x					x	
258	572.4	Haines			x	x		x					x					x	
259	572.4	Canol			x	x		x					x					x	
260	574.7	Trail			x	x		x					x					x	
261	576	Trail			x	x		x					x					x	
262	578	Stream			x	x	x							x	x				
263	578	Haines			x	x	x							x	x				
264	578	Haines			x	x	x							x	x				
265	580.3	Stream	x	x		x				Fan			x					x	
266	583.5	Peat	x	x			x							x				x	
267	584.1	Haines			x	x				Fan			x					x	
268	584.1	Stream			x	x				Fan			x					x	
269	584.1	Haines			x	x				Fan			x					x	
270	585.8	Stream			x	x				Fan			x					x	
271	586	Haines			x	x		x					x					x	
272	587.1	Haines			x	x		x					x					x	
273	587.2	Stream			x	x				Fan			x					x	
274	588.3	Haines			x	x		x					x					x	
275	588.4	Haines			x	x		x					x					x	
276	589.8	Stream			x	x				Fan			x					x	
277	592.5	Stream			x	x				Fan			x					x	
278	594.1	Canol			x	x		x					x					x	
279	594.5	Stream	x	x						Fan			x			x			
280	596	Stream	x	x						Fan			x			x			
281	596.6	Trail	x	x			x							x		x			
282	596.8	Highway	x	x			x							x		x			
283	596.8	Canol				x		x					x					x	
284	598	Haines				x		x					x					x	
285	599.2	Stream				x		x					x					x	
SPREAD TOTALS			12	47	62	58	30	25	0	16	0	1	50	20	6	27	0	42	3

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IROQUOIS RESEARCH INST
WORKSHEET 1455- 02

ALCAN PIPELINE CROSSING INFORMATION INVENTORY- PROJECT 1455

ITEM NO	MILE POST	CROSSING TYPE	SOIL: ORGANIC	SOIL: SILT	SOIL: SAND	SOIL: GRAVEL	TERRAIN: FLOOD PLAIN	TERRAIN: TERRACE	TERRAIN: MOUNT	TERRAIN: OTHER	SLOPE: STEEP	SLOPE: MOD.	SLOPE: GENTLE	SLOPE: NONE	PERMAFROST: NONE	PERMAFROST: ICE RICH	PERMAFROST: ICE POOR	PERMAFROST: DISCON-TINUOUS	PERMAFROST: OTHER
286	600.6	Stream				x		x					x					x	
287	603.5	Peat	x	x				x					x					x	
288	608.2	Highway		x	x	x		x					x					x	
289	608.2	Haines		x	x	x		x					x					x	ice segregations
290	608.5	Canol		x	x	x		x						x				x	" "
291	609.9	Haines		x	x	x	x							x				x	" "
292	610	Stream		x	x	x	x							x				x	" "
293	610.1	Haines		x	x	x	x						x					x	" "
294	613.3	Stream		x	x	x		x					x					x	
295	615.3	Stream		x	x	x		x					x					x	
296	616.5	Stream		M	M	x		x					x					x	
297	616.8	Haines				x		x					x					x	
298	617.5	Stream		M	M	x		x					x					x	
299	618	Haines				x		x					x					x	
300	618.9	Stream		M	M	x		x					x					x	
301	619.5	Stream		M	M	x		x					x					x	
302	623.4	Stream		M	M	x		x					x					x	
303	625.6	Peat	x	x				x					x					x	
304	626.2	Highway				x		x					x					x	
305	626.2	Canol				x		x					x					x	
306	626.2	Haines				x		x					x					x	
307	630	Peat	x	x			x							x				x	
308	631.5	Canol				x		x					x					x	
309	631.5	Trail				x		x					x					x	
310	631.6	Canol				x		x					x					x	
311	633	Road				x		x					x					x	
312	636.6	Road				x		x					x					x	
313	636.6	Road				x		x					x					x	
314	636.7	Road				x		x					x					x	
315	643.7	Road				x		x					x					x	
316	646.5	Stream		x	x	x		x					x					x	
317	648.6	Stream		x	x	x		x					x					x	
318	652.5	Channel		x	x	x	x					x						x	
319	654.7	Stream		x	x	x	x							x				x	
320	656.6	Highway			x					Dunes			x					x	
321	664.1	Haines			x					Dunes		x						x	
322	665	Haines			x					Dunes		x						x	
323	665	Canol			x					Dunes		x						x	
SPREAD TOTALS																			

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IROQUOIS RESEARCH INST
WORKSHEET 1455- 02

ALCAN PIPELINE CROSSING INFORMATION INVENTORY- PROJECT 1455

ITEM NO	MILE POST	CROSSING TYPE	SOIL: ORGANIC	SOIL: SILT	SOIL: SAND	SOIL: GRAVEL	TERRAIN: FLOOD PLAIN	TERRAIN: TERRACE	TERRAIN: MOUNT	TERRAIN: OTHER	SLOPE: STEEP	SLOPE: MOD.	SLOPE: GENTLE	SLOPE: NONE	PERMAFROST: NONE	PERMAFROST: ICE RICH	PERMAFROST: ICE POOR	PERMAFROST: DISCON-TINUOUS	PERMAFROST: OTHER
324	665.4	Haines			x					Dunes		x						x	
325	665.4	Canol			x					Dunes		x						x	
326	666.9	Haines			x					Dunes		x						x	
327	668.4	Highway			x					Dunes		x						x	
328	668.4	Haines			x					Dunes		x						x	
329	668.4	Canol			x					Dunes		x						x	
330	672.3	Highway			x					Dunes		x						x	
331	672.3	Canol			x					Dunes		x						x	
332	672.3	Haines			x					Dunes		x						x	
333	675.7	Stream			x	x				Dunes		x						x	
334	676.4	Road			x					Dunes		x						-x	
335	679.8	Haines			x					Dunes		x						x	
336	681.3	Haines			x					Dunes		x						x	
337	681.4	Haines			x					Dunes		x						x	
338	681.5	Haines			x					Dunes		x						x	
339	681.5	Stream			x					Fan			x					x	
340	682.5	Stream			x	x				Dunes		x						x	
341	684.5	Highway			x					Dunes		x						x	
342	684.7	Stream			x	x				Fan			x					x	
343	685.1	Highway			x					Dunes		x						x	
344	685.1	Haines			x					Dunes		x						x	
345	686	Haines			x					Dunes		x						x	
346	687.2	Stream			x	x				Fan			x					x	
347	688	Trail		x	x	x		x					x					x	
348	688.7	Stream		x	x	x		x					x					x	
349	693.3	Haines		x	x	x		x					x					x	
350	693.4	Highway		x	x	x		x					x					x	
351	693.4	Canol		x	x	x		x					x					x	
352	694.7	Stream		x	x	x		x					x					x	
353	695.9	Haines		x	x	x		x					x					x	
354	696.8	Haines		x	x	x		x					x					x	
355	698.2	Haines		x	x	x		x					x					x	
356	698.5	Haines		x	x	x		x					x					x	
357	700.4	Stream		x	x	x		x					x					x	
358	703.5	Haines		x	x	x		x					x					x	
359	703.6	Trail		x	x	x		x					x					x	
360	705.1	Haines		x	x	x		x					x					x	
SPREAD TOTALS																			

RTE. DOC. ALCAN Z2 SPREAD NO. 6 PREPARED BY Jim Erlandson DATE 8/25/76 PAGE 12 OF 13 PAGES

IROQUOIS RESEARCH INSTITUTE
WORKSHEET 1455- 02

ALCAN PIPELINE CROSSING INFORMATION INVENTORY- PROJECT 1455

ITEM NO	MILE POST	CROSSING TYPE	SOIL				TERRAIN				SLOPE				PERMAFROST				
			ORGANIC	SILT	SAND	GRAVEL	FLOOD PLAIN	TERRACE	MOUNT	OTHER	STEEP	MOD.	GENTLE	NONE	NONE	ICE RICH	ICE POOR	DISCON-TINUOUS	OTHER
361	706.6	Stream		x	x	x		x					x					x	
362	716.3	Stream		x	x	x				Hills		x						x	
363	717.7	Stream		x	x	x				Hills		x						x	
364	717.8	Highway		x	x	x				Hills		x						x	
365	717.8	Haines		x	x	x				Hills		x						x	
366	717.8	Canol		x	x	x				Hills		x						x	
367	718.2	Stream		x	x	x				Hills		x						x	
368	719.1	Haines		x	x	x				Hills		x						x	
369	721.2	Stream		x	x	x				Hills		x						x	
370	725.9	Stream		x	x	x				Hills		x						x	
371	727.8	Stream		x	x	x	x							x				x	
372	728.6	Highway		x	x	x	x							x				x	
373	728.6	Canol		x	x	x	x							x				x	
SPREAD TOTALS			3	47	71	62	9	38	0	36	0	33	47	8	0	0	0	88	5

REF. DOC. ALCAN Z2 SPREAD NO. 6 PREPARED BY Jim Erlandson DATE 8/25/76 PAGE 13 OF 13 PAGES

IRCQUOIS RESEARCH INST.
WORKSHEET 1455-02

ALCAN PIPELINE CROSSING INFORMATION INVENTORY -TOTALS - PROJECT 1455

SPREAD NO.	SOIL				TERRAIN				SLOPE				PERMAFROST				
	ORGANIC	SILT	SAND	GRAVEL	FLOOD PLAIN	TERRACE	MOUNT.	OTHER	STEEP	MOD.	GENTLE	NONE	NONE	ICE RICH	ICE POOR	DISCONTINUOUS	OTHER
SPREAD 1	20	25	25	22	6	18	1	0	0	4	14	7	2	23	0	0	25
SPREAD 2	4	49	53	50	26	8	10	12	6	17	33		24	27	5	0	35
SPREAD 3	0	77	77	77	3	24	11	39	0	28	45	0	24	17	34	0	39
SPREAD 4	0	63	60	49	26	3	2	31	0	20	41	2	15	22	17	9	18
SPREAD 5	12	47	62	58	30	25	0	16	0	1	50	20	6	27	0	42	3
SPREAD 6	3	47	71	62	9	38	0	36	0	33	47	0	0	0	0	88	5
TOTALS	39	308	348	318	100	116	24	134	6	103	230	37	68	119	56	139	125

REF. DOC. ALCAN 72 PREPARED BY JIM ERLANDSON DATE AUGUST 25, 1976

APPENDIX C. LETTER FROM

CONSULTANT WELDING ENGINEER,

MR. JACK BAKER, DATED 8/31/76.

JACK BAKER
Consulting Engineer
P.O. Box 34179 • Omaha, Nebraska 68134 • Telephone: 1-402-393-8138

Via FEDERAL EXPRESS

Mr. R. G. Shutt
Project Manager
IROQUOIS RESEARCH INSTITUTE
Suite 215
6201 Leesburg Pike
Falls Church, Virginia 22044

August 31, 1976

Dear Mr. Shutt:

Appended you will find a series of questions dealing with the various facets of welding an arctic pipeline. As you have been advised verbally before, I do not feel that the ALCAN Exhibit submitted to me contains enough "meat" where welding is concerned to do anything with, and in light of this, two options were available, namely: write a welding procedure for these steels or prepare a set of general questions applicable to welding arctic pipelines, in general. You will observe that I have elected the latter course. Additionallly, the radiography material was in a similar state, so a few questions applicable to this discipline were included also.

It also seems essential to reiterate here that I have discussed the fundamental problem associated with an arctic gas pipeline, particularly one carrying Prudhoe Bay gas, with you, namely: decompression phenomena and the propagating shear fracture. The solution of this problem is manifest in the pipe specification, which we devoted no attention to whatever, pursuant our discussion with your Mr. Nutt.

There are similar aspects of the hydrostatic testing procedure proposed by ALCAN; specifically, the maximum test pressure of 95%SMYS is below that which has been used by progressive gas companies for many years. It more nearly parallels that being used by ALYESKA PIPELINE SERVICE COMPANY, however, but they are constructing a liquid line, not a gas pipeline.

We trust that this information will be suitable for your need, but if you have further questions, please advise.

Sincerely,

Jack Baker

Jack Baker

Attachments

WELDING QUESTIONS

1. What are the specific details of the "effective welding procedure" mentioned in the second paragraph of 3.5? In particular, describe: the base metal(s) welded; the welding process used; the diameter and wall thickness of the pipe welded; the diameter and wall thickness of the pipe welded; the joint design, including bevel preparation and root opening or "space" used; the AWS classification and size of the electrode and/or wire used; the voltage and amperage range used with each pass, including electrical polarity; the position of the pipe axis and the direction of welding; the time lapse between beads, and in particular, the time interval between depositing the stringer bead and hot pass; the type of line-up clamp used and that point in the welding sequence when the clamp was removed; any preheat and interpass temperature requirements adhered to during the test; the speed of travel used for the various passes and was there any restriction on the amount of filler metal consumed per incremental length of bead deposited, especially the stringer bead?

2. Was there a deliberate attempt made to evaluate this "effective welding procedure" under severe conditions by making the initial test welds with "high side" chemistry material?

3. How many complete girth welds were made to come to the conclusion that this "effective welding procedure" was in fact "effective?" Were these welds made on pipe nipples in a laboratory or warehouse, or were they made on full joints of pipe in the field?

4. What variations or differences in the welding procedures are contemplated to cope with the various types of steel (e.g. accicular ferrite, pearlite reduced and low-carbon) mentioned as possible candidates for this project? Is it conceivable that the results of welding tests would markedly influence, if not dictate, the choice of material used for pipe? If so, describe the plan for evaluating the weldability of the various candidate materials prior to ordering the pipe.

5. Welder discipline, in terms of substandard quality workmanship or welds, has received considerable attention recently in conjunction with another arctic pipeline. How do you propose to avoid a reoccurrence of such a situation in conjunction with your project? Will individual workmen be disqualified for making substandard welds? If so, how many substandard welds do you feel should be accepted before a particular individual is disqualified? Will each individual leaving substandard work be required to eliminate his own mistakes, or will the repair function be assigned to a particular welder?

WELDING QUESTIONS
(continued)

6. How many welds do you contemplate making to develop, investigate or prove out a given welding procedure for a particular material or process? Will these welds be made on 42"O.D. x 0.600" wall API Grade 5LX X-65 pipe nipples or with full lengths of pipe? Will welding procedure development work be done in the field under typical Alaskan pipeline construction conditions? Will the development work deliberately select "high-side" chemistry pipe such that one investigates the "worst case" situations?

7. Section 6.3.2 (f) of the ALCAN Exhibit Z2-3.5, PIPELINE CONSTRUCTION PROCEDURES-Line-up and Weld, states that an internal line-up clamp will be used except at tie-ins. At what point during the welding sequence will this clamp be released? Will the welding procedure require deposition of passes or partial passes in addition to the stringer bead before the clamp is released? Will any constraint be placed upon the magnitude of pipe movement permissable when the joint contains only a stringer bead?

8. This provision (e.g. Section 6.3.2 (f), ALCAN Exhibit Z2-3.5) also stipulates that "preheat as required" will be used. But a previous provision, namely: 3.5, alludes to the fact that the assistance of Lincoln Electric Company is being sought to develop welding procedures. Since Lincoln Electric Company's technical brochures for both their Shield-Arc 65+ and X-70 electrode recommend preheat to 300^{O}F prior to welding when the pipe temperature is 70^{O}F or lower, in view of the usual Alaskan ambient temperatures below 70^{O}F, does it not follow that practically all the pipe will be preheated to 300^{O}F prior to the onset of welding? Is this not in conflict with the third paragraph of 3.5? Elaborate?

9. At what point during the welding cycle will preheat be measured? How frequently will it be measured? How will it be measured, and what locations will be monitored? Will there be any interpass temperature control requirement in the welding procedure?

10. Describe the advantages and disadvantages of preheat as it applies to Arctic pipeline welding.

11. Will the welding specifications involve a minimum girth weld toughness requirement? If not, why not? If so, what will be the girth weld toughness criteria, and what specimen(s) will be used to evaluate it? Will sufficient specimens be tested to establish the toughness at various temperatures in the weld metal, heat-affected-zone and unaffected base metal? If not, why not?

12. Will the welding specifications set forth a maximum allowable hardness for the weld metal, heat-affected-zone and base metal? If so, what will the criteria for maximum allowable micro-hardness be, and how will it be measured? If a maximum allowable micro-hardness is not being specified in the welding specifications, what is the logic behind this omission?

13. How will quality control be invoked during production welding? Describe the number of welding inspectors to be used on the project and their various functions. What do you consider to be an acceptable reject rate for production welds? Describe the corrective action to be instituted if and when this reject rate is exceeded. What disciplinary steps will be invoked to insure that construction supervisors, inspectors and welders are all quality conscious? Will construction be halted on any spread where the weld reject rate exceeds the allowable limit?

14. At what frequency will production welds be cut from the pipeline and subjected to mechanical testing? What corrective action will be instituted if these production test welds exhibit mechanical properties below those required by the welding specifications? Will the mechanical tests include toughness and hardness determination as well as the conventional tests delineated in API Std. 1104, Thirteenth Edition?

15. What distance or time lag will be permitted between that point when a production weld is made and when it is X-rayed? Will the work be halted if this constraint is violated?

16. Do you contemplate a need to back-weld the 42"O.D. girth welds in order to meet the Standards of Acceptability set forth in Section 6, API Std. 1104, Thirteenth Edition? If so, why? Do you consider failure to meet the stated quality requirements (e.g. Section 6, API Std. 1104) a manifestation of poor workmanship?

17. Will special procedures be developed for repair welding? What special or unusual problems are contemplated in conjunction with repair welding?

18. Describe the various features of your overall quality control program that will insure that all welds buried do, in fact, comply with the Standards of Acceptability set forth in Section 6, API Std. 1104, and thus required by CFR Title 49, Part 192.

WELDING QUESTIONS
(continued)

19. Do you contemplate repairing cracked girth welds, as would be permissible according to Paragraph 7.4, API Std. 1104 subject to OPSO approval or do you plan to cut out all cracked girth welds?

20. Will double-jointing operations take place inside or outside a building? Who will be responsible for making this determination?

21. What precautions will be taken to cope with inclement weather during construction to preserve the integrity of the production girth welds?

X-RAY QUESTIONS

1. The first paragraph of Section 3.7, ALCAN Exhibit No. Z-2-3.7, states X-ray inspection will be performed on all (100%) pipeline girth welds. (This statement is taken to mean that the less sensitive Gamma-ray radiography will be excluded from use.) Will this X-ray inspection also utilize the more sensitive single wall or internal exposure technique too? What Class of radiographic film will be used? Will lead intensifying screens be used exclusively? Will densitometer readings be employed to determine if the film is of suitable quality to meet the density requirements delineated in API Std. 1104?

2. How long will the radiographic film be retained? What controls will be exercised to insure the radiographic film is properly developed to provide this useful life?

3. How will the radiographs or exposed film be identified so that it can be correlated with a given weld in the pipeline? Will each weld in the pipeline bear permanent identification that can be used by a layman to correlate it with a given radiograph? Describe the salient features of the identification system in detail.

4. What steps will be taken to insure that all welds are radiographed; that film is properly interpreted, and that no duplicate radiographs of the same weld are made (e.g. no falsifications).

5. Describe the disposition procedure for correcting or removing welds rejected as a result of radiographic examination.

6. Will security procedures be instituted to insure that radiographs, particularly those of rejected welds, are not lost, misplaced or stolen? Describe the essential features of these security procedures.

7. Will radiographic interpretations be reviewed, either in toto or on a spot check basis, by a representative of the owner company? (In cases of disagreement, whose interpretation will prevail?)

8. When a weld is known to be defective to the point where a repair is required, who will mark the location of the defect on the pipe.

9. Will notched comparator shims, as shown in Figure 17, API Std. 1104, be used as an attempt to establish the depth of internal undercut or will this depth be measured mechanically?

10. How many Level II Radiographers do you contemplate using on a given construction spread?

APPENDIX D. LETTER FROM
CONSULTANT METALLURGIST,
DR. CHARLES M. GILMORE,
DATED 9/1/76.

Dr. Charles M. Gilmore
9725 Schreiner Lane
Great Falls, Virginia 22066

September 1, 1976

Iroquois Research Institute
Suite 215
6201 Leesburg Pike
Falls Church, Virginia 22044

Dear Sirs,

This letter contains my analysis of the materials and testing proposed in the Alcan Pipeline Project (APP) Pipeline Stress Analysis Executive Summary submitted by Energy Systems Engineering Ltd. on June 30, 1976. In particular I will comment on the Gulf Interstate Engineering Company specification for large diameter high test line pipe (Docket No. CP 76- , Exhibit Z2-3.4).

I propose in the following letter analysis to explain why I am convinced that this proposed design is sure to result in failure because the designers have overlooked the changes that occur in the properties of steel as the steel operating temperature is lowered below normal ambient temperature. Also, the designers have proposed a testing procedure that is meaningless in relation to this proposed design.

In the APP Pipe Stress Analysis Executive Summary on page 2 paragraph 2.4 the statement is made that the actual operating temperature of the pipe could be as low as -60°F. Thus it must be assumed in any analysis or testing procedure that -60°F will be a possible metal temperature. The authors of this report however have not taken into account in their analysis that most steels change from being tough and resistant to cracking at normal ambient temperatures (above 30°F) to being brittle like glass at low temperatures. Materials Engineers call this a ductile to brittle transition. At -60°F steels become brittle and will break like glass with very little resistance to fracture. The steel proposed for this project will most certainly be brittle since this class of steel has a transition from ductile to brittle behavior at about 32°F. This same ductile to brittle transition resulted in welded steel ships breaking catastrophically in half in the North Atlantic Ocean, so Materials Engineers are well aware of these problems.

The designers of gas pipe lines also are aware of the problem of fracture of welded pipe and for this reason specification API 5LX and API 5LS have been developed to evaluate the fracture resistance of steel pipe. However, these specifications were developed for pipe that was operating in the warmer climate of the United States and not for the cold of the Arctic. An important test for measuring the resistance to fracture of the pipe metal is the Charpy V Notch Impact Test. This test measures the energy necessary to fracture the metal in service, and the energy should be measured under conditions approximating as closely as possible the actual service environment. However, API 5LX and 5LS both specify that the Charpy Test be run at either 32°F or 50°F. No test of the pipe steel is proposed at -60°F which could be an operating temperature. At -60°F the Charpy V Notch Impact energy of the steel proposed in this pipe should be nearly zero, ie. zero resistance to fracture. The ~~test~~ outlined in API 5LX and 5LS that are run at 32°F or 50°F are meaningless for an determining fracture resistance in an actual service environment of -60°F.

Some recognition of low temperature behavior does appear in exhibit Z2-3.4 where Charpy V Notch tests are proposed on the weld metal at 0°F, and the drop weight tear test is also to be conducted at 0°F, but again both of these tests provide meaningless information if the actual pipe temperature was much lower such at -60°F. Also the hydrostatic test is meaningless unless it is conducted at the actual operating temperature.

The tests that are indicated in exhibit Z2-3.4 provide meaningless information because they are not conducted at the actual operating temperature, a steel could pass all of these tests and still fracture like brittle glass at actual service temperatures.

The designers of this pipe however are relying upon this pipe being ductile and not brittle for they are depending upon ductile plastic deformation to relieve strains caused by earth quakes as described in paragraph 3.3 of the APP Pipe Stress Analysis Executive Summary. Ductile plastic deformation of this pipe at temperatures approaching $-60^{0}F$ are sheer fantasy, it will be as brittle as glass.

I cannot be too strong in my conclusion that this design would be a sure failure. I have discussed this conclusion with other experts on pipeline materials and there seems to be no question that these designers have made a gross oversight in trying to use welded steel at these proposed low temperatures.

Sincerely yours,

C. M. Gilmore, Ph.D.

Resume' attached

APPENDIX E. MAGNITUDE OF SOME EFFECTS OF CERTAIN POSSIBLE PIPELINE FAILURE MODES: DR. JOHN P. ZARLING, AUGUST 1976

Possible Gas Pipeline Failure Mode No. 1.

Discussion:

If a rupture and subsequent ignition of the escaping gas on the proposed gas pipeline occurred, what would the effect be on the oil pipeline?

The Mechanical Engineering Handbook by Baumeister and Marks gives the flame temperature of methane burning with 80% to 140% theoretical air as 4050 degrees R to 3330 degrees R, respectively. Since it is a well-known fact that the strength of steel decreases rapidly at elevated temperatures, the effects of exposing the oil pipeline and VSM's to a natural gas fire could conceivably result in structural failure.

Recommendations:

1. The Applicant should attempt to predict the occurrence probability of a catastrophic event such as the discussed rupture and subsequent ignition of escaping natural gas.

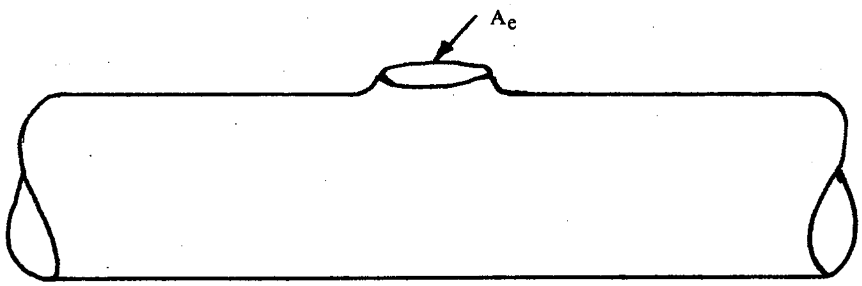
2. The Applicant should determine the potential hazards of exposing the oil pipeline to a natural gas fire.

Possible Gas Pipeline Failure Mode No. 2.

Discussion:

What effects will result from a pipe rupture during the operation of the proposed gas line?

Assuming the gas pipeline is 42" O.D. and 41" I.D., contains methane gas at $10^{o}F$ and 1250 psia, determine the initial thrust produced by a rupture.



Applying a momentum balance to a control volume of a ruptured section of the pipeline yields

$$T = \dot{m}_f V_e + A_e(P_e - P_A)$$

where T is thrust

$\dot{m}_f$ is mass flow rate of gas

V_e is exit velocity of gas

A_e is cross-sectional area of rupture

P_e is exit pressure

P_A is ambient pressure

Further assuming isentropic flow and ideal gas conditions yields the following relations between the stagnation and exit plane conditions

$$\frac{T_0}{T_e} = 1 + \frac{K - 1}{2} M^2$$

$$\frac{P_0}{P_e} = \left(1 + \frac{K - 1}{2} M^2\right)^{K/K - 1}$$

$$\frac{\rho_0}{\rho_e} = \left(1 + \frac{K - 1}{2} M^2\right)^{1/K - 1}$$

where M is the Mach number. From the First Law of Thermodynamics the exit velocity, V_e, can be calculated

$$V_e = \sqrt{2g_c J c_p (T_0 - T_e)}$$

For the conditions stated above, the flow will be choked since the pressure ratio is less than critical and therefore the Mach number will be equal to one at the exit. Using the following property values for Methane

$$R = 96.4 \text{ ft.-lb.}_f/\text{lb.}_m - {}^oR$$

$$K = 1.3$$

$$C_p = .532 \text{ Btu/lb.}_m - {}^oR$$

$$T_0 = 470^oR$$

$$P_0 = 1250 \text{ psia}$$

The exit velocity, pressure, and density are calculated as

$$V_e = 1278 \text{ ft./sec.}$$

$$P_e = 682.3 \text{ psia}$$

$$\rho_e = 2.492 \text{ lb./ft.}^3$$

Calculating the initial thrust on a per square foot of rupture area gives

$$T = 2.225 \times 10^5 \text{ lb.}_f/\text{ft.}^2 \text{ of rupture}$$

If the weight of a foot of pipe is 220 pounds and the weight of methane gas per foot of pipe is 36 pounds then initial thrust from a one square foot break in the bottom of the pipe would be sufficient to lift 870 feet of pipeline. A break of 4 square feet would be sufficient to initially accelerate the same length of line upward at 4g's.

Conclusions:

This analysis only evaluated the initial thrust of an ideal gas flowing through a hole in the pipe wall. The results should provide an upper bound to the thrust created by a pipe rupture. A less conservative model would account for real gas effects such as nozzle efficiency, nozzle discharge coefficient, decrease in stagnation temperature and pressure as the gas discharges through the rupture, and Fanno flow of the gas in the pipeline to the ruptured area. See for example: Transport Phenomena, Bird, Stewart, and Lightfoot, pg. 405.

Recommendation:

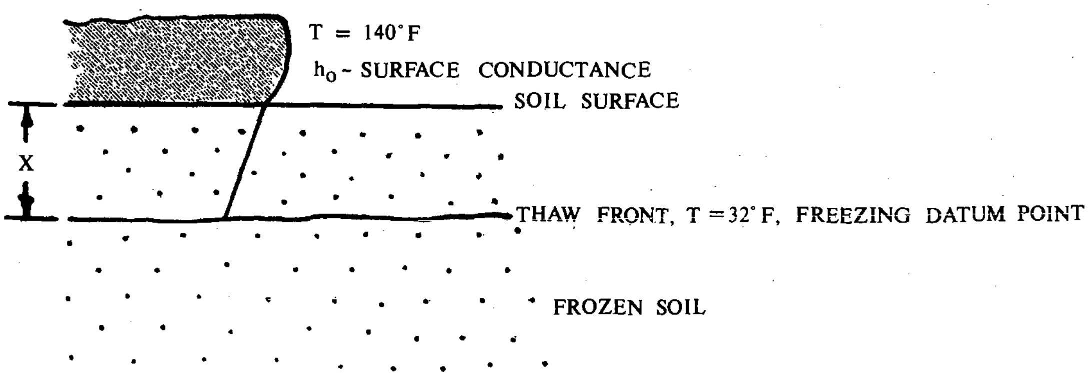
Due to the possible magnitude of the thrust caused by a rupture of the gas pipeline, a more detailed investigation should be carried out on the rupture mechanism. If a literature survey does not provide sufficient design information to ensure against catastrophic conditions, then a detailed analytical model should be constructed and laboratory or field tests conducted.

Possible Gas Pipeline Failure Mode No. 3.

Discussion:

What effect will a rupture in the Trans Alaska oil pipeline have on the thermal regime of the frozen soil surrounding the proposed gas pipeline?

Since the valves on the oil pipeline are located approximately 13 miles apart, a rupture of this line could potentially cause a spill of 8.27×10^5 cubic feet (1.47×10^5 barrels) of 140°F crude oil. To estimate the depth of thaw caused by a spill of this magnitude a simplified heat transfer model is constructed.



The rate of heat transfer to the thaw front is

$$q = \frac{\Delta T}{\Sigma R} = \frac{\Delta T}{\frac{1}{h_0} + \frac{x}{k}}$$

Assuming this energy is totally used in thawing the soil, then

$$q = \frac{\Delta T}{\frac{1}{h_0} + \frac{x}{K}} = \rho L \frac{dx}{dt}$$

Solving the differential equation for t and applying the boundary condition that no thawing has occurred at time zero yields

$$t = \frac{\rho L}{\Delta T}\left(\frac{x}{h_o} + \frac{x^2}{2K}\right)$$

where ρL is the volumetric latent heat

ΔT is the temperature potential

h_0 is the surface conductance

x is the thaw depth

t is time

K is thermal conductivity of thawed soil

Using physical properties of frost susceptible soils (silt) given in Heat Exchange at the Ground Surface, R. F. Scoot, CRREL Report II-A1, and assuming Alaska crude oil is similar in physical properties to other crudes, the depth of thaw was calculated. In carrying out this calculation it was also assumed that the duration of the spill was 24 hours. During that time, the oil discharged from the line was assumed to be flowing down a 5% slope and spreading out to a 30 feet width as it crossed in the vicinity of the gas pipeline.

Based on the above assumptions, the thaw depth after 24 hours is presented as a function of soil moisture content as follows:

Soil Type	Moisture Content	Depth of Thaw
Silt	10%	1.4 feet
Silt	20%	1.2 feet
Silt	30%	1.1 feet

If the duration of the spill lasted for four days this would have the effect of doubling the thaw depth.

This analysis seems to indicate that a major oil pipeline break will not have a detrimental effect on the integrity of the frozen soil surrounding the gas pipeline. However, a small undetected leak of the oil line, persisting for a long time, may have adverse effects.

Recommendations:

1. The Applicant should consult with Alyeska to determine the magnitude of flow rates for undetected oil spills. A similar heat transfer analysis could then be carried out to ascertain the long-term thermal effects for these low flow rate leaks.

2. Infiltration of the hot oil into the ground and its effects on the frozen soil surrounding the gas line has not been considered. An analysis of this mechanism of heat transport should be performed.

GLOSSARY OF TECHNICAL TERMS

active layer	a surface layer of ground (or soil) above the permafrost, that is alternately frozen each winter and completely thawed each summer.
aggregate (concrete)	hard, fragmentary material (usually rock) mixed with cement to make concrete.
Alaskan Native	Indian, Eskimo, and Aleut as defined in Section 3, ALASKA NATIVE CLAIMS SETTLEMENT ACT, Dec. 13, 1971.
albedo	the percentage of incident light that is reflected by a natural surface such as ground, water, snow, or ice.
alignment	detailed location of the proposed pipeline; supported by specific data.
all-terrain vehicle (ATV)	self-propelled vehicle, usually equipped with tracks or special tires, capable of traveling off roadways.
alluvial	consisting of, or formed by sand or mud left by flowing water.
alluvial fan	a low, relatively flat to gently sloping deposit of alluvium shaped at the surface like an open fan (but actually a segment of a cone) and laid down by a stream at the place where it issues from a narrow mountain valley upon a plain or broad valley.
alluvial plain	a plain resulting from the deposition of silt, sand, and gravel by water.
alluvium	unconsolidated geologic materials deposited from the running water in which they were transported.
Alyeska	the corporate name of a consortium of companies building the trans-Alaska oil pipeline system.
ambient temperature	the temperature of the surrounding air in which an activity takes place.
anchor	structures, frequently piles, affixed to pipelines to restrain lateral or vertical movements.

annulus (frozen)	ring of frozen soil surrounding a chilled pipeline in unfrozen ground.
annular ice bulb (frost bulb)	ring of frozen soil surrounding a chilled pipeline in unfrozen ground.
aquifer	a rock formation, bed or zone containing water that is available to wells. An aquifer may be referred to as a water-bearing formation or water-bearing bed.
Arctic Slope	that area north of the continental divide of the Brooks Range within Alaska (see North Slope).
ATV	see all-terrain vehicle.
aufeis	a layered sheet of ice formed on a surface: (1) on a river flood plain when shoals in the river freeze or are otherwise dammed so that water spreads over the flood plain and freezes; (2) layered ice formed on ground surface, highways, etc. as a result of seepage from hillsides or flow from springs.
axial flow	surface or subsurface flow of water directed parallel to the long axis of the pipeline in or on top of a backfilled pipeline ditch.
backfill	material used to replace material removed during construction.
backfill mound	a ridge located above a backfilled pipeline ditch.
backhoe	an excavating machine.
bedding (engineering)	select fill material placed under an object to provide uniform bearing; (geology)--stratification in sedimentary or volcanic rocks.
bedrock	rock that has undergone no major change through the effects of weathering and erosion at the surface of the earth; commonly overlain by surficial material.
berm	a ledge or shoulder; the coverage over a pipe that has an elevation above the surrounding landscape.
biochemical oxygen demand (BOD)	the measure of the quantity of dissolved oxygen, in milligrams per litre, used for the decomposition of organic matter by microorganisms, such as bacteria.
biota	all living things, both plants and animals.
biotic	pertaining to life or living things.

block valve — a valve capable of completely closing off gas flow in a pipeline.

blowdown — 1. clearing of gas from pipeline by blowing it into the atmosphere. 2. a pipe or valve used to vent gas to the atmosphere. 3. the procedure whereby the gas pressure is intentionally reduced in a section of the line by venting. It is accomplished by the operation of valves and closure fittings provided in each block valve assembly.

blowdown valve — a mechanism for venting gas into the atmosphere to eliminate pressure in the pipeline.

bog — an acidic, mineral-deficient, peat-filled or peat-covered wetland, usually having vegetation of peat moss (Sphagnum spp.), sedges, heath shrubs and scattered black spruce and tamarack.

bog soil — any one of an intrazonal group of poorly drained soils with a muck or peaty surface underlain by peat.

borehole — a hole drilled into the earth to determine subsurface conditions.

boring — to make a hole by sinking a hole or tunneling underground.

borrow — any earthen, granular, or rock material taken from one area for use in another.

braided stream — a stream flowing in several dividing and reuniting channels resembling the strands of a braid, the cause of the division being the obstruction by sediment deposited by the stream; where more sediment is being brought to any part of a stream than it can remove, the building of bars becomes excessive and the stream develops an intricate network of interlacing channels.

breakup — in general, the spring melting of snow, ice, and frozen ground; specifically, the destruction of the ice cover on rivers during the spring thaw; or applied to the time when the solid sheet of ice on rivers breaks into pieces that move with the current; breakup connotes the end of winter to residents of the North.

capacity peaking — the capacity of facilities or equipment normally used to supply incremental gas under extreme demand conditions.

cathodic protection	a method of preventing corrosion of steel pipe and components by causing an electrical current to flow from the soil to the pipe.
centerline (pipeline)	a line in the vertical plane that longitudinally bisects a pipeline.
channel (watercourse)	an open conduit, natural or artificial, which periodically or continuously contains moving water.
cleanup	soil and gravel materials scraped and collected from winter roads, spoil lanes, etc., that were spilled or left during construction.
climate	the sum total of the meteorological elements that characterize the average and extreme condition of the atmosphere over a long period of time at any one place or region of the earth's surface; a history of weather.
climatic	pertaining to climate.
climax	the relatively stable, terminal plant and animal community of a successional series which is in a state of dynamic equilibrium with the regional climate.
colluvium	a general term applied to loose heterogeneous rock or soil material deposited by gravity on or below a steep slope.
computer model	a mathematical simulation of a physical process that is generally solved using a digital or analogue computer.
compressor	a piece of machinery used for increasing the pressure of a gas.
compressor station	a facility which supplies the energy to move gas in transmission lines or into storage by increasing the pressure.
construction materials	naturally occurring mineral commodities used in construction; in this statement they are sand, gravel, crushed rock, and material used for riprap.
construction spread	a portion of the pipeline system that constitutes a complete physical entity in and of itself, and that can be constructed independently of any other portion of the pipeline system in a designated area, or between two given geographical points, reasonably proximate to one another.

construction year	a system of numbering calendar years in which the year in which construction commences is year 1, and succeeding years are numbered consecutively.
continuous permafrost	permafrost occurring everywhere beneath the exposed land surface throughout a geographic regional zone with the exception of widely scattered sites, such as newly deposited unconsolidated sediments, where the climate has just begun to impose its influence on the ground thermal regime and will cause the formation of continuous permafrost.
contracted reserves	natural gas reserves dedicated to the fulfillment of gas purchase contracts.
corridor	see alternative corridor.
creep	the slow, gradual, more or less continuous, non recoverable deformation sustained by ice, soil, and rock materials under gravitational body stresses.
crosstie	section of pipe used to connect two parallel pipelines.
culvert	a drain or channel crossing under a road
cut-graded slopes	a portion of a natural slope which has been flattened by excavation to provide an operating surface for wheeled or track laying construction vehicles and equipment.
cut grading	to reduce to a level or to a practicable degree of inclination by excavating.
db(A)	a unit for measuring sound which takes into account the frequency of a sound as well as the intensity. See also decibel.
deep creep	see creep.
dense-phase	this term is applied to fluids that are in a single phase but exhibit properties between those of a liquid and a gas. Natural gas exhibits the dense-phase property within a pressure range of approximately 400 to 1,000 pounds per square inch gauge, and a temperature range of approximately -115°F to -150°F.

depletion	the progressive withdrawal of water from surface- or ground-water reservoirs at a rate greater than that of replenishment.
depth of cover	the vertical thickness of backfill between the top of the pipe and ground surface.
design scour elevation	generally the depth below maximum stream scour based on formula and (or) field measurement of scour during peak flow conditions.
dewatering	the temporary removal of water from an excavation.
dewpoint	the temperature at which a gas begins converting to the liquid state.
dig-in	damage to an underground facility by construction equipment.
discharge	in its simplest concept discharge means outflow: therefore, the use of this term is not restricted as to course or location, and it can be applied to describe the flow of water from a pipe or from a drainage basin. If the discharge occurs in some course or channel, it is correct to speak of the discharge of a canal or of a river.
discontinuous permafrost	permafrost occurring in some areas beneath the ground surface throughout a geographic regional zone where other areas are free of permafrost.
dissolved solids	total quantity of solids present in solution quantitatively expressed as milligrams per litre; typically the residue on evaporation.
distributary branch or line	synonym of distribution line.
distribution line	pipeline from a trunk line to an existing gas pipeline system or to a gas consumer.
ditch	the excavation in which a pipeline is buried.
ditch block	an obstruction used at frequent intervals along a drainage ditch to prevent water erosion.
ditch plug	an impervious barrier placed across the pipeline ditch to prevent subsurface axial water flow in the ditch.

ditching	the act or method of opening and cleaning a trench for pipe placement.
diversion ditches	trenches which redirect water flow to another location.
divide, drainage	the elongate, commonly sinuous, zone or line that separates river, lake or ocean drainage basins.
double jointing	the welding of two joints (lengths) of pipe together.
dragline	an excavation machine in which the bucket is attached only by cables and is drawn toward the machine during the excavation or filling process.
drainage area	the drainage area of a stream at a specified location is that area, measured in a horizontal plane, which is enclosed by a drainage divide.
drainage basin	a part of the surface of the earth that is occupied by a drainage system which consists of a surface stream or a body of impounded surface water together with all tributary surface streams and bodies of impounded surface water.
dry gas	gas whose water content has been reduced by a dehydration process; or gas produced from a well not in conjunction with oil production.
earth buttress (toe loading)	a mass of soil or rock placed at the toe of a slope as a stabilizing measure.
ecology	the study of the interrelationships between organisms and their environment.
ecosystem	a natural, integrated, self-sustaining community of organisms interacting with each other and their total abiotic environment in a dynamic system independent of all external energy and material sources except the input of solar radiation.
environment	all external physical and biological factors, either individually or collectively, which act upon or are served by living organisms.
environmental quality	the properties and characteristics of the environment.
epicenter	that point on the earth's surface which is directly above the focus of an earthquake.

erodibility	the degree of susceptibility of soil to removal by water or wind.
erosion	the process whereby earth materials are loosened or dissolved and removed from a part of the earth's surface; by running water, waves, ice, and winds, it includes weathering solution, corrosion, and transportation.
escarpment	a long, more or less continuous cliff or relatively steep slope facing in one general direction, breaking the general continuity of the land by separating two level or gently sloping surfaces, and produced by erosion or by faulting.
factor of safety	a factor relating the computed stresses in a structure to the failure stress.
failure	in the environment sense, the melting away or loss of berm and fill materials by natural forces such that the system deviates from that specified and constructed.
fault	a surface or zone of rock fracture along which there has been movement; total movement may range from microscopic to many miles.
fault zone	a relatively long and narrow band on the surface of the earth comprising numerous faults and fractures, and that is the expression of a single fault or fault system at depth.
faulting	the process of rock fracturing and displacement that produces a fault.
flood plain	a strip of relatively smooth land bordering a stream, built of sediment carried by the stream and dropped in the slack water beyond the influence of the swiftest current.
flotation cylinder	a closed cylindrical vessel attached to a pipe to provide positive buoyancy during installation of pipe at river crossings.
flow formula	a formula for determining the flow of gas between any two points in a pipeline under various conditions.
focal depth	distance from earthquake focus to the surface of the earth.

focus (earthquake)	the point within the earth which is the center of an earthquake and the origin of its elastic waves.
fold	a curve or bend in a planar geologic element such as a stratum or joint.
folding	the curving or bending of a planar feature, such as a stratum; see fold.
footing	the widening of a structure at its base to spread the load over a large area of the underlying soil.
freeze crack	a crack of varying depths in the soil resulting from extreme temperature changes in frozen ground.
freezeup	the time when temperatures generally are below freezing and ice covers are formed on rivers; to northerners, the beginning of winter.
freezing front	the surface at the boundary of a mass of frozen soil at which freezing is taking place.
french drain	ditch filled with gravel or other coarse materials which allow free drainage of sub-surface water.
frost action	the process of alternate freezing and thawing of water in soils and rock and the resulting effects on materials and structures.
frost boil	an accumulation of excess water and mud liberated from ground ice by accelerated spring thawing, commonly softening the soil and causing a quagmire.
frost bulb	the mass of frozen soil surrounding a pipe containing gas at a temperature below 32°F.
frost front	generally assumed to be the 32 degrees F or 0 degrees C isotherm.
frost heaving	the lifting of a ground surface caused by the freezing of internal moisture.
frost-susceptible soil	soil in which significant detrimental ice segregation occurs when the requisite moisture and freezing conditions are present.
frozen ground	soil or rock having a temperature below 32°F (0°C).
fuels	naturally occurring mineral commodities commonly used as sources of heat; examples are coal, natural gas, and oil.

full burial	the development of a ditch, placement of pipe, and coverages with soil or other materials such that the top of the pipe is below the level of the original ground surface.
gas field	a tract or district yielding natural gas.
gathering station	place where gas is gathered from underground gas storage or from a producing natural gas field and inserted into the pipeline transmission system for distribution.
gelifluction	a synonym for congelifluction which is the progressive and lateral flow of earth materials under periglacial conditions; solifluction in a region underlain by frozen ground.
geotechnical study	an investigation of geologic conditions to determine the constraints they impose on construction designs.
girth welds	welds joining two sections of pipe together.
gradient	1. slope, particularly of a stream or a land surface; measurements expressed in percent, feet per mile, or degrees. 2. change in value of one variable with respect to another variable, especially vertical or horizontal distance, e.g. gravity, temperature, magnetic intensity, electrical potential, etc.
gravel	unconsolidated deposits of rounded rock fragments larger than sand; more than 0.83 inch in diameter.
ground cover	the amount of vegetation covering the ground surface expressed by species types, biomass, or percent coverages.
ground heaving	upward movement of the ground surface as a result of the formation of ground ice in excess of pore space.
ground ice	all ice, of whatever age or origin, found beneath the surface of the ground, especially in perennially frozen ground.
ground settlement (sometimes subsidence or slump)	downward movement of the ground resulting from the melting of excess ground ice.
ground thermal regime	the distribution and change of temperature and heat flux within the ground.

ground water	water in the ground that is in the zone of saturation, from which wells, springs, and ground-water runoff are supplied.
ground-water outflow	that part of the discharge from a drainage basin that occurs through the ground water. The term "underflow is often used to describe the ground-water outflow that takes place in valley alluvium (instead of the surface channel) and thus is not measured at a gaging station.
habitat	the place and its total environmental complex where a plant, animal, or community or organisms lives.
heat flux transducer	an instrument which utilizes a miniature thermal pile, to measure the heat flowing across a structure.
holiday	a discontinuous or flawed area in the coating of a pipe.
hydrological regime	the average behavior over a period of time of a stream with naturally varying discharge, breadth, depth, velocity, sediment load, meander pattern, etc.
hydrology	the science that relates to the water of the earth.
hydrostatic test	the application of a predetermined fluid pressure to the interior of a pipe to test its ability to withstand the specified test pressure over a prescribed time period.
hypocenter	the sub-surface source of an earthquake.
ice bulb	see annular ice bulb.
ice fog	a type of fog composed of minute ice crystals; forms at low air temperature inversion; three factors are necessary for ice fog to form; (a) a temperature lower than -25°F, (b) a source of water, and (c) particulates in the air that form nuclei for droplet and ice particle condensation.
ice lens	1. a dominantly horizontal lens-shaped body of ice of any dimension; 2. commonly used for layers of segregated ice that are parallel to the ground surface. The lenses may range in thickness from a hairline to more than 50 feet.

ice-rich permafrost	perennially frozen ground that contains ice in excess of that required to fill pore spaces.
ice road	a surface consisting of packed snow that has been strengthened by spraying with water.
ice wedge	a massive, generally wedge-shaped body with its apex pointing downward, composed of foliated or layered, vertically oriented, commonly white ice.
ice-wedge polygon	any polygonally shaped piece of ground bounded by ice wedges; commonly from a few to several tens of feet in diameter.
icing	a mass of surface ice formed by successive freezing of sheets of water that seep from the ground, from a river, or from a spring. River icings are formed from waters of the river itself, building up over the existing river ice and sometimes extending beyond the river channel onto the flood plain. Ground icings are formed on the ground surface when an obstruction blocks normal ground water flow. Spring icings are formed by water flowing from a spring.
impact	any change in existing physical, biological, or cultural conditions that would ensue if the proposed gas pipeline system were built, operated, and abandoned.
in situ	refers to in-place conditions.
indigenous	that which is native to a region, as contrasted with that which is imported and alien.
input parameters	the parameters required to be input into computer or equation solutions such as thermal conductivity, latent heat, heat capacity, water content, unit weight, etc.
intensity (earthquake)	the measure of the effects of an earthquake on man and/or engineering structures; commonly measured on the modified Mercalli scale.
interstice	a small or narrow space or interval between things or parts; pore.
intrapermafrost water	free water occurring in unfrozen zones within the permafrost.

inversion, temperature	the condition which exists in the atmosphere when warm air is above cooler air. Ground-based inversions caused by radiative cooling and cold air drainage are common in the Arctic, especially in winter.
isotherm	on a map, a line connecting points of equal temperature.
joint (pipeline)	a length of pipe as supplied from the manufacturer.
Joule-Thomson effect	in passing a gas at high pressure through a porous plug or small aperture, a difference of temperature between the compressed and released gas usually occurs. The phenomenon is called the Joule-Thomson effect. The equation for this effect is $\left(\frac{\partial T}{\partial P}\right)_H = \frac{T\left(\frac{\partial V}{\partial T}\right)_P - V}{C_P}$
lacustrine deposits	sediments deposited in a lake; commonly fine grained and in thin beds.
laminar flow (or fluid flow)	strictly, flow with constant separation of streamlines, so that constant velocity surfaces remain at constant separation and lamina or sheets of fluid slide over one another.
liquefied natural gas (LNG)	a clear, flammable liquid principally composed of methane. Natural gas must be cooled to -260°F in order to produce LNG and its volume occupies 1/600 of the volume of gas.
load	the volume of gas delivered or required at any specified point in a system. (also, demand)
loess	a widespread, homogeneous, commonly nonstratified, unconsolidated but slightly coherent deposit generally laid down by the wind and consisting predominantly of silt with subordinate grain sizes ranging from clay to fine sand.
magnitude (earthquake)	a measure of the strength of an earthquake, or the strain energy released by it, as determined by seismograph measurements. (See Richter scale)
Main Line	the trunk line of the Applicant's proposed system.
mass wasting; mass movement	movement of material down a slope by the force of gravity.

meander	1. One of a series of somewhat regular and looplike bends in the course of a stream, developed when the stream is flowing at grade, through lateral shifting of its course toward the convex sides of the original curves. 2. A land survey traverse along the bank of a permanent natural body of water.
meander scar	an abandoned meander, often filled in by deposition and vegetation, but still discernible (especially from the air).
meltwater	water resulting from the melting of snow or of glacier ice.
methanol	methyl (wood) alcohol (CH_3OH).
microwave	an electromagnetic wave of extremely high frequency, usually having wavelength of from 1mm to 50 cm.
Mile Post	a point on a route that is the numbered distance, in miles, from a point of beginning.
mobilization	movement of supplies and equipment and readying for work at a construction site.
muck	unconsolidated mixture of silt and well-decomposed organic material.
mudflow	a viscous, downslope-moving mixture of sediment and water which is capable of transporting pebbles, cobbles and boulders.
muskeg	a bog, usually a sphagnum bog frequently with tussocks of deep accumulation of organic material, growing in wet, poorly drained, boreal regions, often areas of permafrost.
native backfill	soil or rock excavated from the pipe trench and placed around the pipe after installation.
north slope	the Arctic Coastal Plain or tundra regions of the North Slope
North Slope	that area north of the continental divide of the Brooks Range within Alaska.
odorant	a chemical compound (mercaptan) used to give a perceptible odor to natural gas which has no natural odor of its own.
off-peak	period during a day, week, month, or year when the load being delivered by a gas system is not at or near the maximum volume.

operating year	a system of numbering calendar years in which the first year of gas transmission is numbered 1, and succeeding years are numbered consecutively.
organic silt	see muck.
organic terrain	a tract of land comprised of a superficial layer of living material (vegetation) and various hydrological and underlying mineral formations.
outcrop	the exposure of bedrock at the surface of the earth.
outwash	stratified unconsolidated deposits composed chiefly of sand and gravel that have been "washed out" from a glacier by meltwater streams and deposited in front of or beyond its terminal moraine or outer margin.
outwash train (or valley train)	a long, narrow body of outwash, deposited by meltwater streams beyond the terminal moraine or the margin of a glacier and confined within the walls of a valley below the glacier.
overbend	upward bend in vertical plane and purposely made or resulting from stress.
over-break	excessive shattering or excavation resulting from blasting.
overburden	barren rock material. usually unconsolidated, overlying a deposit of useful materials, and which must be removed prior to mining.
overstressing	loading a structure to the point that the maximum fibre stress exceeds the allowable working stress.
oxbow lake	a crescent-shaped lake formed in abandoned river bend which has become separated from the main stream by a change in the course of the river.
padding	select fill material around a pipe to provide protection to the pipe and coating during backfill. Also called bedding.
partial burial	the development of a ditch, placement of pipe, and coverage with soil or other materials such that the top of the pipe is either even with or higher than the original ground level.
particulate matter	minute separate particles. With respect to air pollution, these particles are airborne.
particulates	see particulate matter.

peat	raw or partially decomposed plant remains preserved as organic deposits largely under anaerobic conditions of wetlands; also accumulating in cold climates by low temperature preservation.
peat moss	species of the genus Sphagnum.
peat plateau	a low, generally flat-topped expanse of peat, rising 3 feet or more above the general surface of a peatland. A layer of permafrost exists in the peat plateau and may extend into the peat below the general peatland surface and even into the underlying mineral soil.
perennially frozen ground (or soil)	see permafrost.
permafrost	soil, rock, or any other earth material whose temperature remains below $32^{o}F$ ($0^{o}C$) continuously for 2 or more years.
permafrost aggradation	an increase in thickness and/or areal extent of permafrost because of natural or artificial causes as a result of climatic cooling and/or change of terrain conditions, such as vegetation succession or infilling of lakes.
permafrost degradation	a decrease in thickness and/or areal extent of permafrost because of natural or artificial causes as a result of climatic warming and/or change of terrain conditions such as disturbance or removal of an insulating vegetation layer by fire or human means.
permafrost regression	the melting of the permafrost to a depth greater than the maximum thaw of the active layer; usually the result of altered moisture, insulation, or energy-absorbing conditions.
permafrost table	the upper boundary of permafrost.
permeability	capacity of rock or soil for transmitting a fluid. Degree of permeability depends upon the size and shape of pores, their interconnections and the extent of the latter. Permeability is measured by the rate at which a fluid of standard viscosity can move a given distance through a given interval of time. The customary unit of permeability is the millidarcy.
pig	a device sent through a pipeline for internal cleaning, separating transmission products of different types, or other purposes.
ponding	forming ponds by the blocking of natural drainage courses.

population	the total individuals of a species, or of a mixture of species, in an area.
pothole	a shallow depression, generally less than 10 acres, occurring between dunes on a prairie, often containing an intermittent pond or marsh and serving as a nesting place for waterfowl.
pressure limiting station	equipment that prevents pressure in a pipeline from exceeding the maximum allowable operating pressure by controlling the flow of gas.
pressure relief station	equipment that prevents the pressure in a pipeline from exceeding the maximum allowable operating pressure by venting gas to the atmosphere.
proposed route	the pipeline route proposed by the Applicant in the submittal documents.
purging	clearing water or other substances from a pipeline.
radiographic testing	the use of x-rays or other rays to produce an image to determine weld integrity.
re-injection	the process of injecting a gas or fluid into the underground reservoir from which the gas or fluid was originally produced or removed.
residual material	soil removed from ditch in which pipeline is to be placed.
resources	a concentration of naturally occurring solid, liquid, or gaseous materials in or on the earth's crust in such form that economic extraction of a commodity is currently or potentially feasible. Resources include materials that have been identified but cannot now be extracted because of economic or technological factors, as well as, economic or subeconomic materials that are yet to be discovered.
retrogressive flow slides	a landslide form, peculiar to permafrost, which develops with a characteristic bi-angular cross section. The steep head-scarp region retrogresses into ice-rich soil and the low angle tongue transports melted debris and water downslope.
Reynolds Number	$\frac{\text{scale velocity x scale length}}{\text{kinematic viscosity}}$, same for all liquids at critical velocity.
Richter scale	the range of numerical values of earthquake magnitude. In theory there is no upper limit to the magnitude of an earthquake, but the strength of earth materials produces an actual upper limit of slightly less than 9. The scale is logarithmic.

riparian	related to the bank of a body of water.
riser	general term for a vertical run of gas piping, normally rising to an above-ground system from a below-ground system.
route	a routing for the proposed pipeline; the Applicant has provided alignment sheets depicting routes.
runoff	that part of the precipitation that appears in surface streams. It is the same as streamflow unaffected by artificial diversions, storage, or other works of man in or on the stream channels.
saddle weights	weights, usually of concrete, that straddle pipe, and which have no clamps or bolts, that are used to provide negative buoyancy.
sag bend	a vertical bend made in pipe and placed in a concave upward position to allow it to conform to the contour of the ditchline.
sag point	the lowest point of a pipe in a concave downwards bend.
schist	a strongly foliated crystalline rock formed by dynamic metamorphism, and which can be readily split into thin flakes or slabs.
scrubber, gas	equipment used to remove condensate from gas.
secondary stress	a secondary stress is a normal stress or a shear stress developed by the constraint of adjacent parts or self-constraint or a structure. The basic characteristic of a secondary stress is that it is self-limiting.
security river crossing	parallel section of pipeline installed at river crossings for emergency use only.
sediment	fragmented material that originates from weathering and erosion of rocks and is transported by, suspended in, or deposited by water or air or is accumulated in beds by other natural agencies.
sediment discharge	the rate at which sediment, as measured by dry weight, passes a section of a stream; or the quantity of sediment, as measured by dry weight, that is discharged in a given time.
sediment load	the amount of suspended matter in a stream.

sedimentation	the action or process of depositing sediment.
seismic	pertaining to an earthquake or earth vibration.
seismicity	the phenomenon of an earthquake or earth vibration.
seismograph	an instrument to record earth vibrations.
select backfill	backfill for which a specification has been established specifying gradation limits and/or composition.
sensitive permafrost	perennially frozen ground whose temperature is only slightly below 32°F (0°C); sometimes referred to as "warm" permafrost.
shrink sleeve	a conformable sleeve that is shrunk in place around a field-welded joint of pre-coated pipe by applying heat.
side bend	pipeline bend in the horizontal plane purposely made or resulting from stress.
side ditches	drainage channels built on one or both sides of a road.
sideboom crawler tractor	a large track laying tractor with a boom attached to one side used for lifting, holding, transporting, or placing pipe.
silt	1. A clastic sediment, most of the particles of which are between 62 micrometers and 4 micrometers in diameter. 2. Soil consisting of 80 percent or more silt (0.05 - .002mm) and less than 12 percent clay.
siltation	the deposition or accumulation of silt that is suspended throughout a body of water; often includes sedimentary particles ranging in size from colloidal clay to sand.
sink (hole)	a circular or ellipsoidal depression formed on the surface of limestone terrain.
slump	a mass of earth material that has moved down a slope.
snow road	a temporary access road constructed by leveling and packing snow to the required depth and density to support traffic.
snowmelt runoff	runoff primarily responding to melting snow during the spring months, sometimes called spring runoff, or breakup.

soil	that upper portion of surficial materials capable of supporting plant growth. Used by soils engineers for all materials above bedrock.
soil profile	succession of zones or horizons beginning at the surface that have been altered by normal soil-forming processes of which leaching and oxidation have been particularly important.
solifluction	the process of slow, gravitational, downslope movement of saturated, nonfrozen earth material behaving apparently as a viscous mass over a surface of frozen material.
sound attenuation	a reduction in sound level.
specification	a detailed description of requirements, dimensions, materials, etc., as of a building, machine, bridge, or other structure.
spoil	any earth or rock material that has been excavated.
spoil berm	an embankment of excavated material located on the non-working part of a pipeline right-of-way.
spoil lane	the place where excavated materials from ditching are put; usually opposite the access and construction road.
spoil mound	an earthen terrace over a pipeline.
sporadic permafrost	permafrost occurring in the form of scattered islands of perennially frozen ground.
spread	a group of workers and necessary equipment organized to handle all phases of construction for a given pipeline section.
step increase in temperature	a sudden change in temperature such as when the pipeline is started up.
stone polygons	a form of patterned ground whose mesh is dominantly polygonal and has a sorted appearance commonly due to a border of stones surrounding finer material.
stone stripes	a sorted stripe consisting of coarse rock debris, and occurring between wider stripes of finer material; oriented down the steepest available slope.
strata	refers to the soil layering-ice wedge; soil system in effect at test site.
streamflow	may be the same as runoff but is a more general term including flow affected by diversion or regulation.

stringing	the transportation of pipe from stockpiles to the right-of-way and its placement on the right-of-way parallel to the ditch in preparation for welding.
subpermafrost water	free water in the ground below the permafrost base.
subsidence	settling or sinking of ground.
supply line	pipeline from a gas field to a trunk line.
suprapermafrost layer	the layer of ground above the permafrost, consisting of the active layer and, wherever present, taliks.
suprapermafrost water	free water in the ground above the permafrost.
surcharge	a higher than normally applied load; in the case of a buried pipe, extra backfill covering the pipe.
surface water	water on the land surface in streams, lakes, and reservoirs.
surficial	at the surface of the earth; commonly applied to geologic materials above hard bedrock.
system integrity	refers to the ability of the pipeline test sections to remain in an as-designed condition.
talik	a Russian term for unfrozen ground beneath the active layer above, within, or beneath the permafrost.
thaw consolidation ratio	a dimensionless parameter, which is a measure of the relative rates of generation and expulsion of excess pore fluids in a thawing soil.
thaw front	the surface at the boundary of a mass of frozen soil at which thawing is taking place.
thaw lake	in regions underlain by permafrost, a shallow body of water whose basin is produced by settlement of the ground following thawing of ground ice.
thaw-stable soil	soil initially below 32°F and which when warmed above 32°F does not appreciably change in shear strength or bearing capacity.
thermal	of, relating to or caused by heat.
thermal erosion	settling or slumping following melting of permafrost.
thermal niche erosion	river bank erosion caused by undercutting and slumping following melting of permafrost at water level.

thermokarst	the irregular topography resulting from differential thaw settlement or caving of the ground because of the melting of ground ice in non-thaw stable permafrost.
throughput	the quantity of natural gas or other product transported by pipeline.
top soil	an expression for overlying soil material containing plant growth. In the Arctic coastal plain, this is primarily peaty material of partially decomposed plant and root material.
tundra	an ecosystem characterized variously by low-growing vegetation of mosses, lichens, grasses and sedges, and dwarf shrubs; such animals as lemmings and other microtine rodents, caribou, musk oxen and grizzly bears; occurring in the Arctic beyond the latitudinal limit of trees and in mountains above the timber line.
unconsolidated material	a sediment whose particles are not cemented together.
valve	a mechanical device used to start, stop, or regulate the flow of gas through the pipeline.
valve operator	the source of mechanical energy used to open or close valves.
vegetation	the plants covering the surface of the earth or the act or process of vegetating.
venting	releasing gas in a pipeline section to the atmosphere through valves. Also blowdown.
wash	the dry bed of an intermittent stream.
water table	the upper surface of a zone of saturation. No water table exists where that surface is formed by an impermeable body.
wet gas	natural gas deposits found in association with oil deposits.
wetlands	any terrain having the water table at or near the ground surface.
winter road	any managed or unmanaged surface of snow, ice, or barren ground that is used by vehicles only during the winter.

withdrawal use of water	the water removed from the ground or diverted from a stream or lake for use.
working lane	working side of pipeline right-of-way.

SELECTED BIBLIOGRAPHY

Selected Bibliography

1. Aamot, Haldor W. C. and Schaefer, David. May-June 1972. "Roofs for Cold Regions," The Military Engineer, No. 419: 158-160.

2. Alaskan Arctic Gas Pipeline Company. March 21, 1974. Application of Alaskan Arctic Gas Pipeline Company at Docket No. CP 74-96 for a Certificate of Public Convenience and Necessity.

3. ________. January 21, 1976. Comments of Alaskan Arctic Gas Pipeline Company on Federal Power Commission Staff Draft Environmental Impact Statement on Alaskan Natural Gas Transportation Systems.

4. ________. January 21, 1975. "Design Criteria, Design Specifications and Design Analysis."

5. Alaska Arctic Gas Study Company. March 16, 1974. Geology of the Pipeline Routes in Alaska. Calgary, Alberta: Canadian Arctic Study, Ltd.

6. Alcan Pipeline Company. July 9, 1976. Application of Alcan Pipeline Company at Docket No. CP76-96 for Certificate of Public Convenience and Necessity.

7. ________. 1976. Prepared Direct Testimony and Hearing Exhibits.

8. Alter, Amos J. October 1969. Sewerage and Sewage Disposal in Cold Regions, Monograph III-C5b. Hanover, New Hampshire: U.S. Army Cold Regions Research and Engineering Laboratory.

9. ________. January 1969. Water Supply in Cold Regions, Monograph III-C5a. Hanover, New Hampshire: U.S. Army Cold Regions Research and Engineering Laboratory.

10. American Gas Association. December 1962. Manual for the Determination of Supercompressibility Factors for Natural Gas, PAR Research Project NX-19: Extension of Range of Supercompressibility Tables. U.S.A.: American Gas Association.

11. American Petroleum Institute. February 1968. "API Recommended Practice for Internal Coating of Line Pipe for Gas Transmission Service," API RP 5L2, 1st edition. Washington, D.C.: American Petroleum Institute.

12. ________. March 1975. "API Specification for High-Test Line Pipe," API Spec 5LX, 20th edition. Washington, D.C.: American Petroleum Institute.

13. ________. March 1975. "API Specification for Spiral-Weld Line Pipe," API Spec 5LS, 8th edition. Washington, D.C.: American Petroleum Institute.

14. ________. September 1968. "Recommended Practice for Liquid Petroleum Pipelines Crossing Railroads and Highway," API RP 1102, 4th edition. Washington, D.C.: American Petroleum Institute.

15. ________. July 1973. "Standard for Welding Pipe Lines and Related Facilities," API Std. 1104, 13th edition. Washington, D.C.: American Petroleum Institute.

16. American Standards Association. 1968. Gas Transmission and Distribution Piping Systems, USAS-B31.8. New York: The Society of Mechanical Engineers.

17. ________. 1971. Liquid Petroleum Transportation Piping Systems, ANSI-B31.4. New York: The Society of Mechanical Engineers.

18. Anderson, D.M.; Crowder, W.K.; et al. June 1973. An ERTS View of Alaska Regional Analysis of Earth and Water Resources Based on Satellite Imagery, Technical Report 241. Hanover: U.S. Army Cold Regions Research and Engineering Laboratory.

19. Anderson, D.M.; McKim, H.L.; et al. February 1974. Artic and Subartic Environmental Analyses Utilizing ERTS-1 Imagery, Final Report Contract No. S-70253-AG. Hanover: U.S. Army Cold Regions Research and Engineering Laboratory.

20. Anderson, D.M.; Tice, Allen R. 1972. "Predicting Unfrozen Water Contents in Frozen Soils from Surface Area Measurements." Highway Research Record 393: 12-18.

21. Ashton, George D. 1973. "Heat Transfer to River Ice Covers," Proceedings of the 30th Annual Meeting of the Eastern Snow Conference, pp. 125-135.

22. Baumeister, Theodore and Marks, Lionel S. 1967. Standard Handbook for Mechanical Engineers. New York: McGraw Hill Company, 4th edition.

23. Behlke, Charles E. and McKay, A. Ronald. August 1971. "Artificial Ice for Arctic Marine Structures," Paper 7104. Paper presented at the American Society of Civil Engineers National Meeting in Seattle, Washington, July 30, 1971.

24. Benedict, J. B. "Downslope Movement in a Colorado Alpine Region: Rates, Processes, and Climatic Significance."

25. Bilello, Michael A. and Bates, Roy E. June 1972. Ice Thickness Observations, North American Artic and Subartic, 1968-69, 1969-70, Special Report 43, Pt. VI. Hanover: U.S. Army Cold Regions Research and Engineering Laboratory.

26. Brown, J. and Sellman, P. V. September 1973. "Permafrost and Coastal Plain History of Arctic Alaska," Technical Paper No. 25, Alaskan Arctic Tundra:31-47.

27. Brown, Jerry. 1973. "Environmental Considerations for the Utilization of Permafrost Terrain." Permafrost: The North American Contribution to the Second International Conference, ISBNO-309-02115-4. Washington, D.C.: National Academy of Sciences, pp. 587-590.

28. __________, Rickard, Warren; and Vietor, Donald. November 1969. The Effect of Disturbance on Permafrost Terrain. Special Report 138. Hanover: U.S. Army Cold Regions Research and Engineering Laboratory.

29. Brown, Jerry and West, George C. November 1970. Tundra Biome Research in Alaska: The Structure and Function of Cold-Dominated Ecocystems, USIBP-Tundra Biome, Report 70-1.

30. Brown, R. J. E., and Johnson, G. H. "Permafrost and Related Engineering Problems," Endeavor, Volume 23, Number 89: 66-72.

31. Carey, Kevin L. May 1973. Icings Developed From Surface Water and Ground Water. Monograph III-D3. Hanover: U.S. Army Cold Regions Research and Engineering Laboratory.

32. Champion, Charles A. February 6, 1975. "Assessment of Project Status, Trans Alaska Pipeline," Paper from State of Alaska, Office of the Pipeline Coordinator.

33. Condo, A. C., McGrogan, J. F., and Burt, Glenn R. 1971. "Insulated Gravel Embankments for Arctic Road Construction," Paper No. APE 3378. Paper prepared for Southwest Alaska Section Regional Meeting of the Society of Petroleum Engineers of AIME, Anchorage, Alaska, May 5-7, 1971.

34. Crawford, C. B. and Johnson, G. H. 1971. "Construction on Permafrost," Canadian Geotechnical Journal, Vol. 8, No. 23

35. Crory, Frederick E. February 1968. Bridge Foundations in Permafrost Areas: Goldstream Creek, Fairbanks, Alaska, Technical Report 180. Hanover: U.S. Army Cold Regions Research and Engineering Laboratory.

36. __________. December 1973. Installation of Driven Test Piles in Permafrost at Bethel Air Force Station Alaska, Technical Report 139. Hanover: U.S. Army Cold Regions Research and Engineering Laboratory.

37. _________. March 1967. Pile Foundations in Discontinuous Permafrost Areas, Special Report 79, Hanover: U.S. Army Cold Regions Research and Engineering Laboratory.

38. _________. "Pile Foundations in Permafrost." Proceedings: Permafrost International Conference, NAS-NRC, Publication 1287: 467-476.

39. _________. November 1972. "Settlement Associated with the Thawing of Permafrost." Paper prepared for Second International Conference on Permafrost, Yakutsk, USSR, July 1973.

40. Dingman, Lawrence. June 1973. The Water Balance in Arctic and Subarctic Regions, Annotated Bibliography and Preliminary Assessment, Special Report 187. Hanover: U.S. Army Cold Regions Research and Engineering Laboratory.

41. EBA Engineering Consultants, Ltd. May 1976. "Preliminary Thermal Input Parametrics for Flow Studies in Gas Pipeline from Prudhoe Bay to the Yukon Border via Fairbanks," Sect. V.

42. El Paso Alaska Company. September 23, 1974. Application of El Paso Alaska Company at Docket No. CP75-96 for a Certificate of Public Convenience and Necessity.

43. Perrians, Oscar J. Jr.; Dachadoorian, Reuben; and Greene, Gordon W. 1969. Permafrost and Related Engineering Problems in Alaska. Geological Survey Professional Paper 678. Washington, D.C.: Government Printing Office.

44. Fryer, Mark W. 1970. The Buried Pipe Problem (Quick Solutions to Selected Problems in Heat Transfer). Bulletin 7002. College, Alaska: Institute of Arctic Environmental Engineering, University of Alaska.

45. Fulwider, Charles W. and Stearman, Jay H. April 1968. A Bibliography on Winter Construction 1940-1967. Special Report 83. Hanover: U.S. Army Cold Regions Research and Engineering Laboratory.

46. Gulf Interstate Engineering Company. June 1976. Preliminary Environmental Impact Assessment of the Proposed Alcan Pipeline. Vol. III.

47. Haugen, R. K.; McKim, H. L.; Gatto, L. W.; and Anderson, D. M. 1972. "Cold Regions Environmental Analysis Based on ERTS-1 Imagery," Proceedings of the 8th International Symposium on Remote Sensing of the Environment, University of Michigan, 2-6 October 1972, pp. 1511-1521.

48. Hayden, H. W.; Moffat, William G.; and Wulff, John. 1965. Structures and Properties of Materials: Mechanical Behavior, Vol. III, New York: John Wiley and Sons, Inc.

49. Hok, Jerome R. 1969. A Reconnaissance of Tractor Trails and Related Phenomena on the North Slope of Alaska. Washington, D.C.: U.S. Department of Interior.

50. Johnson, Phil. 1970. "Fairbanks Temperature Patterns and Frequency of Days in Various Temperature Ranges." Institute of Arctic Environmental Engineering, University of Alaska.

51. Kaplar, Chester W. March 1972. "Cold Weather Excavation and Foundation Work," Draft prepared for presentation at Institute University Extension, The University of Wisconsin, Milwaukee, Wisconsin, February 15-16, 1972.

52. Kays, W. M. Convective Heat and Mass Transfer. New York: McGraw Hill, 1966.

53. Kersten, Miles S. June 1, 1949. Thermal Properties of Soils, Bulletin No. 28. Minneapolis: University of Minnesota Institute of Technology.

54. Keune, R. and Hoekstra, P. July 1967. Calculating the Amount of Unfrozen Water in Frozen Ground From Moisture Characteristic Curves, Special Report 114. Hanover: U.S. Army Cold Regions Research and Engineering Laboratory.

55. Kuesel, T. R. June 1969. "Earthquake Design Criteria for Subways," Journal of the Structural Division, ASCE, Vol. 95, No. ST6: 1213-1231.

56. Lachenbruch, Arthur. 1959. Periodic Heat Flow in a Stratified Medium with Application to Permafrost Problems. U.S.G.S. Bulletin 1083-A. Washington, D.C.: U.S. Government Printing Office.

57. Lappe, M. January 16, 1971. "Ecosystem Impacts and Changes on the North Slope and TAPS Pipeline Route." USDI-TAPS Hearings Supplemental Testimony, Exhibit 68. (Rough Draft)

58. Lent, Peter C. September 15, 1969. "Big Game Populations and Movement Along the Proposed Trans-Alaska Pipeline Route."

59. Linell, K. A.; Hennigan, F. B.; Lobacz, E. F. 1963. "Corps of Engineers' Pavement Design in Areas of Seasonal Frost," Highway Research Record, No. 33: 76-136.

60. Linell, K. A. and Kaplar, C. W. August 1966. Description and Classification of Frozen Soils. Technical Report 150. Hanover; U.S. Army Cold Regions Research and Engineering Laboratory.

61. Linell, K. A. and Johnson, G. H. 1973. "Principles of Engineering Design and Construction in Permafrost Regions," 2nd International Conference: North American Contribution. Washington, D.C.: National Academy of Sciences, pp. 553-575.

62. Lobacz, E. F. and Quinn, W. F. "Thermal Regime Beneath Buildings Constructed on Permafrost." Proceedings: Permafrost International Conference, NAS-NRC. Publication 1287: 247-252.

63. Long, Erwin L. April 1964. "The Long Thermopile," Civil Engineering:

64. McCown, Brent H. May 1973. Growth and Survival of Northern Plants at Low Soil Temperatures, Special Report 186. Hanover: U.S. Army Cold Regions Research and Engineering Laboratory.

65. McGrogan, J. R.; Condo, A. C.; and Neubauer, J. 1971. "Tundra Restoration: Two Year Response Study of Generic Related Grass Types Introduced Onto Disturbed Prudhoe Bay Area Tundra," Paper No. SPE 3378. Paper prepared for Southwest Alaska Section Regional Meeting of the Society of Petroleum Engineers of AIME, Anchorage, Alaska, May 5-7, 1971.

66. Michel, Bernard. June 1970. Ice Pressure on Engineering Structures, Monograph III-Blb. Hanover: U.S. Army Cold Regions Research and Engineering Laboratory.

67. ________. April 1971. Winter Regime of Rivers and Lakes. Monograph III-Bla. Hanover: U.S. Army Cold Regions Research and Engineering Laboratory.

68. National Earthquake Information Center, U.S. Coast and Geodetic Survey. 1970. Earthquake History of Alaska: Earthquake Information Bulletin, Vol. 2, No. 2: 30-35.

69. National Transportation Safety Board, Bureau of Surface Transportation Safety. August 16, 1973. "Pipeline Accident Report -- Atlanta Gas Light Company, Atlanta, Georgia, August 31, 1972." NTSB-PAR-73-3.

70. ________. December 8, 1971. "Pipeline Accident Report -- Colonial Pipeline Company Petroleum Products Pipeline, Jacksonville, Maryland, September 3, 1970." NTSB-PAR-71-2.

71. ________. August 21, 1974. "Pipeline Accident Report -- Columbia Gas of West Virginia, Inc., Charleston, West Virginia, December 2, 1973." NTSB-PAR-74-4.

72. ________. February 19, 1976. "Pipeline Accident Report -- Consolidated Edison Company Explosion at 305 East 45th Street, New York, N.Y. April 22, 1974." NTSB-PAR-76-2.

73. ________. June 30, 1976. "Pipeline Accident Report -- Dow Chemical, U.S.A. Natural Gas Liquids Explosion and Fire, Near Devers, Texas, May 12, 1975." NTSB-PAR-76-5.

74. ________. May 25, 1972. "Pipeline Accident Report -- Equitable Gas Company Natural Gas Distribution System, Pittsburgh, Pennsylvania, November 17, 1971." NTSB-PAR-72-2.

75. ________. August 1973. "Pipeline Accident Report -- Exxon Pipe Line Company Crude Oil Explosion at Hearne, Texas, May 14, 1972," NTSB-PAR-73-2.

76. ________. December 13, 1972. "Pipeline Accident Report -- Lone Star Gas Company, Fort Worth, Texas, October 4, 1972." NTSB-PAR-73-1.

77. ________. November 8, 1972. "Pipeline Accident Report -- Lone Star Gas Company, North Richland Hills, Texas, October 4, 1971." NTSB-PAR-72-3.

78. ________. December 4, 1969. "Pipeline Accident Report -- Low Pressure Natural Gas Distribution System, Gary, Indiana, June 3, 1969."

79. ________. April 2, 1975. "Pipeline Accident Report -- Michigan-Wisconsin Pipe Line Company, Monroe, Louisiana, March 2, 1974." NTSB-PAR-75-1.

80. ________. November 11, 1974. "Pipeline Accident Report -- Mid America Pipeline System Anhydrous Ammonia Leak, Conway, Kansas, December 6, 1973." NTSB-PAR-74-6.

81. ________. April 27, 1976. "Pipeline Accident Report -- Mid-Valley Pipeline Company Crude Oil Terminal Fire Near Lima, Ohio, January 17, 1975." NTSB-PAR-76-3.

82. ________. February 27, 1974. "Pipeline Accident Report -- Missouri Public Service Company, Clinton, Missouri, December 9, 1972." NTSB-PAR-74-3.

83. ________. July 1, 1971. "Pipeline Accident Report -- Mobil Oil Corporation High Pressure Natural Gas Pipeline Near Houston, Texas, September 9, 1969." NTSB-PAR-71-1.

84. ________. May 16, 1973. "Pipeline Accident Report -- Northern States Power Company, Lake City, Minnesota, October 30, 1972." NTSB-PAR-72-2.

85. ________. November 7, 1973. "Pipeline Accident Report -- Phillips Pipe Line Company Natural Gas Liquids Fire, Austin, Texas, February 22, 1973." NTSB-PAR-73-4.

86. ________. March 1, 1972. "Pipeline Accident Report -- Phillips Pipe Line Company Propane Gas Explosion Franklin County, Missouri, December 9, 1970." NTSB-PAR-72-1.

87. ________. February 13, 1974. "Pipeline Accident Report -- Southern Union Gas Company, El Paso, Texas, April 22, 1973." NTSB-PAR-74-2.

88. ________. "Pipeline Accident Report -- Southern Union Gas Company Gas Transmission Pipeline Failure Near Farmington, New Mexico, March 15, 1974." NTSB-PAR-75-3.

89. ________. February 4, 1976. "Pipeline Accident Report -- Texas Oil and Gas Corporation 6-inch Natural Gas Gathering Pipeline Failure, Meridian, Mississippi, May 21, 1974." NTSB-PAR-76-1.

90. ________. May 28, 1975. "Pipeline Accident Report -- Transcontinental Gas Pipe Line Corporation, 30-inch Gas Transmission Pipeline Failure Near Bealeton, Virginia, June 9, 1974." NTSB-PAR-75-2.

91. ________. February 7, 1974. "Pipeline Accident Report -- UGI Corporation, Coopersburg, Pennsylvania, February 21, 1973." NTSB-PAR-74-1.

92. ________. "Pipeline Accident Report -- Washington Gas Light Company, Bowie, Maryland, June 23, 1973." NTSB-PAR-74-5.

93. ________. November 22, 1972. "Pipeline Accident Report -- Washington Gas Light Company Natural Gas Explosions at Annandale, Virginia, March 24, 1972." NTSB-PAR-72-4.

94. ________. June 9, 1976. "Pipeline Accident Report -- West Texas Gulf Pipe Line Company, Abilene, Texas, December 1, 1974." NTSB-PAR-76-4.

95. ________. May 25, 1972. "Special Study -- A Systematic Approach to Pipeline Safety," NTSB-PSS-72-1.

96. ________. December 30, 1970. "Special Study of Effects of Delay in Shutting Down Failed Pipeline Systems and Methods of Providing Rapid Shutdown." NTSB-PSS-71-1.

97. ________. June 7, 1973. "Special Study -- Prevention of Damage to Pipelines," NTSB-PSS-73-1.

98. Newmark, N. M. 1971. "Earthquake Response Analysis of Reactor Structures," Proceedings of First International Conference Structural Mechanics in Reactor Technology, Berlin, Germany, September, 1971.

99. Newmark, N. M. and Hall, W. J. 1974. "Seismic Design Spectra for Trans-Alaska Pipeline," Proceedings--Fifth World Conference on Earthquake Engineering, Vol. I: 554-557.

100. Northwest Pipeline Company. June 9, 1976. Application of Northwest Pipeline Company at Docket No. CP76-435 for a Certificate of Public Convenience.

101. O'Byrne, Joseph. 1974. "Analysis and Design of Thermal Piles for Cold Regions." IR260. Hanover: U.S. Army Cold Regions Research and Engineering Laboratory.

102. Okamoto, Shunzo. 1973. Introduction to Earthquake Engineering. New York: John Wiley & Sons, Chapter 16.

103. Ohsaki, Y. "The Effects of Local Soil Conditions Upon Earthquake Damage," Proceedings of Specialty Session 2, Seventh International Conference on Soil Mechanics and Foundation Engineering, Mexico 1969.

104. Péwé, L. Troy. 1926. "Permafrost Challenge of the Arctic," Department of Geology, Arizona State Reprint Series 194, Yearbook of Science and the Future. Chicago: Encyclopedia Brittanica, Inc.

105. Phukan, A. "Simplified Approach to Slope Stability Analysis in Thawing Soils." Paper presented at Second International Symposium on Cold Regions Engineering, Aug. 13-15, 1976, Fairbanks.

106. ________ and Andersland, O. B. 1976. "Foundations on Cold Regions," Geotechnical Engineering for Cold Regions. New York: McGraw Hill. (in press).

107. Reed, John H. "Pipeline Transportation, A Challenging Future." Address prepared for the Association of Oil Pipe Lines Meeting, June 20, 1972, The Broadmoor, Colorado Springs, Colorado.

108. Rickard, Warren, Jr. and Brown, Jerry. Spring 1974. "Effects of Vehicles on Arctic Tundra," Environmental Conservation, Vol. 1, no. 1: 55-62.

109. Rieger, Samuel, et al. April 1972. Soils of the Caribou-Poker Creeks Research Watershed, Technical Report 236. Hanover: U.S. Army Cold Regions Research and Engineering Laboratory.

110. Ross, G. A.; Seed, H. B.; and Migliaccio, R. R. 1969. "Bridge Foundation in Alaska Earthquake," Journal of the Soil Mechanics and Foundation Engineering, Division A.S.C.E., Vol. 95, No. SM4: 1007-1036.

111. Sanger, Frederick J. June 1969. Foundations of Structures in Cold Regions, Monograph III-C4. Hanover: U.S. Army Cold Regions Research and Engineering Laboratory.

112. Sayles, F. H. September 1966. Low Temperature Soil Mechanics Interim Report 255. Hanover: U.S. Army Cold Regions Research and Engineering Laboratory.

113. Scott, Ronald F. October 1969. The Freezing Process and Mechanics of Frozen Ground, Monograph II-D1. Hanover: U.S. Army Cold Regions Research and Engineering Laboratory.

114. Seed, H. B. 1968. "The Fourth Terzaghi Lecture, Landslides During Earthquakes Due to Liquefaction," Journal of the Soil Mechanics and Foundation Engineering, Division A.S.C.E., Vol. 94, No. S.M.S.: 1053-1122.

115. Sellman, P. V.; Hockstra; and Delaney, A. J. March 1974. Airborne Resistivity Survey Near Fairbanks, Alaska: An Aid in Bedrock Geology Reconnaissance, Special Report 202. Hanover: U.S. Army Cold Regions Research and Engineering Laboratory.

116. Shah, H. H. and Chu, S. L. June 1969. "Seismic Analysis of Underground Structural Elements," Journal of the Power Division, ASCE: 53-62.

117. Sharpe, T. K. Production Modules - Prudhoe Bay Field, Paper No. SPE 3247. Paper prepared for Southwest Alaska Section Regional Meeting of the Society of Petroleum Engineers of AIME, Anchorage, Alaska, May 5-7, 1971.

118. Stearns, S. Russell. August 1966. Permafrost (Perennially Frozen Ground, I-A2. Hanover: U.S. Army Cold Regions Research and Engineering Laboratory.

119. ________. July 1965. Selected Aspects of Geology and Physiography of the Cold Regions, I-A1. Hanover: U.S. Army Cold Regions Research and Engineering Laboratory.

120. Stokes, William P. 1971. "North Slope Construction Criteria, Roads and Facilities," Paper No. SPE 3248. Paper prepared for Southwest Alaska Section Regional Meeting of the Society of Petroleum Engineers of AIME, Anchorage, Alaska, May 5-7, 1971.

121. Tobiasson, Wayne and Redfield, Robert. August 1973. "Alaskan Snow Loads." Paper presented at the 24th Alaskan Science Conference, University of Alaska.

122. U.S. Army. July 1964. Heat Exchange at the Ground Surface, II-A1. Hanover: U.S. Army Cold Regions Research and Engineering Laboratory.

123. U.S. Army. July 1964. Snow and Ice on the Earth's Surface, II-C1. Hanover: U.S. Army Cold Regions Research and Engineering Laboratory.

124. U.S. Army Corps of Engineers. November 1970. SEV Arctic Environment Data Package, Hanover: U.S. Army Cold Regions Research and Engineering Laboratory.

125. U.S. Code of Federal Regulations. April 1, 1976. "Conservation of Power and Water Resources," Title 18, Parts 1-149.

126. U.S. Code of Federal Regulations. October 1, 1975. "Transportation," Title 49, Parts 100-199.

127. U.S. Court of Appeals, District of Columbia Circuit Nos. 72-1796, 72-1797, 72-1798: The Wilderness Society; Environmental Defense Fund, Inc. Friends of the Earth; and David Anderson, Canadian Wild Life Federation; and the Cordova District Fisheries Union, Appellants V. Rogers C. B. Morton, Secretary of the Interior; Earl L. Butz, Secretary of Agriculture; and Alyeska Pipeline Service Company; and State of Alaska, February 9, 1973.

128. U.S. Department of Agriculture. June 1973. "Soil Survey: Salcha-Big Delta Area, Alaska," prepared in cooperation with the University of Alaska Institute of Agriculture Sciences.

129. U.S. Department of Interior. December 1975. A Report to the Congress, Pursuant to Public Law 93-153. Washington, D.C.: U.S. Government Printing Office.

130. U.S. Department of Interior. June 1975. Alaska Natural Gas Transportation System: Draft Environmental Impact Statement.

131. U.S. Department of Interior. December 1975. Alaskan Natural Gas Transportation Systems: Economic and Risk Analysis Conclusions and Results. Washington, D.C.: U.S. Government Printing Office.

132. U.S. Department of Interior. March 1976. Alaska Natural Gas Transportation System--Final Environmental Impact Statement. Washington, D.C.: U.S. Government Printing Office.

133. U.S. Department of Interior. January 1976. Alaska Natural Gas Transportation System Final Geotechnic Evaluation Alaska Pipeline. Washington, D.C.: U.S. Government Printing Office.

134. U.S. Department of Labor, Occupational Safety and Health Administration. June 27, 1974. "Federal Register: Occupational Safety and Health Standards," Volume 39, No. 125, Part II. Washington, D.C.: U.S. Government Printing Office.

135. U.S. Department of Transportation. August 19, 1970. "Federal Register: Transportation of Natural and Other Gas by Pipeline; Minimum Safety Standards," Volume 35, No. 161, Part II. Washington, D.C.: U.S. Government Printing Office.

136. U.S. Department of Transportation, Hazardous Materials Regulations Board. "Part 195 -- Transportation of Liquids by Pipeline." Amdt. 195-1; Docket No. HM-6.

137. U.S. Environmental Protection Agency. November 27, 1973. "Federal Register: Transportation Control Plans," Vol. 38, No. 227, Part II. Washington, D.C.: U.S. Government Printing Office.

138. U.S. Federal Power Commission. April 1976. Alaska Natural Gas Transportation Systems -- Final Environmental Impact Statement. Washington, D.C.: U.S. Government Printing Office.

139. Van Nostrand's Scientific Encyclopedia, 4th edition. Princeton: D. Van Nostrand Company, Inc., 1968.

140. Vyalov, S. S. November 1963. "Rhulogy of Frozen Soils" Proceedings of the Permafrost International Conference, pp. 332-337.

141. Wilson, C. August 1969. Climatology of the Cold Regions, Northern Hemisphere II. Monograph I-A3b. Hanover: U.S. Army Cold Regions Research and Engineering Laboratory.

142. Yong, R. N. and Osler, J. C. 1971. "Heave and Heaving Pressures in Frozen Soil," Canadian GeoTechnical Journal, Vol. 8, No. 2: 272-282.

143. Zhukov, V. F. July 1972. Settling of Thawing Ground, TL 355. Hanover: U.S. Army Cold Regions Research and Engineering Laboratory.