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Environmental Impact Statement

for

Alaska Gas Pipeline Project:

Technical Review of Permafrost-Related Problems

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Introduction

Foothills Pipelines (Yukon) Ltd. made application in 1976 to the National Energy Board for a certificate of public convenience and necessity to construct a natural gas pipeline through the southern Yukon. Foothills Pipelines (South Yukon) Ltd. has prepared an environmental impact statement of the pipeline, now known as the Alaska Highway Gas Pipeline, in response to a series of guidelines issued by an environmental review panel. The completed Environmental Impact Statement is being distributed by the Federal Environmental Assessment and Review Office for the purposes of public and technical comment. Members of the Earth Physics Branch of the Department of Energy, Mines and Resources have been requested to contribute technical comments on the subjects of seismic risk and permafrost hazard. This initial review examines the E.I.S. in terms of permafrost-related topics.

Permafrost underlays much of the region through which the proposed pipeline will be built; extensive widespread permafrost is present between Kluane Lake and the Alaskan border and scattered and sporadic permafrost extends to south of Fort Nelson. The role that permafrost and permafrost-related topics will play in the pipeline design is thus readily apparent.

Review of E.I.S.

The Environmental Impact Statement quite rightly deals at some length, if only in a general way, with permafrost and permafrost-related problems. At this stage many of the details necessary for a careful and complete assessment are unavailable and so discussion and comments must be of a general nature. I believe that Foothills should be congratulated on producing such an excellent preliminary document which touches on many of the serious geotechnical issues raised by a major innovative undertaking of this kind. In many instances specific final details are lacking but excellent illustrative examples are given to outline the design "philosophy".

In this critique of the document we seek to do four things:

a. to suggest aspects of the E.I.S. which could benefit from greater elaboration.
b. to emphasize caution where somewhat simplistic models have been used to illustrate design principles.
c. to identify areas of study not discussed in the E.I.S. which may be relevant to pipeline performance.
d. to further quantify permafrost characteristics where our own very limited data can add to data presented in the E.I.S.

Briefly, I believe that the E.I.S. could benefit considerably from further discussion of the advantages and disadvantages of the operational modes available i.e. buried vs surface vs elevated, chilled vs warm etc...etc. Some operational modes may be more suitable for specific portions of the route than others. For example, the chilled mode will have some obvious advantages in continuous permafrost. The E.I.S. does not provide a clear explanation for the decision to operate in the chilled buried mode over the first 45km from the Alaskan border. Examples of terrain disturbance arising from earlier development projects such as the Haines to Fairbanks oil pipeline and the Alaska Highway would illustrate some of the permafrost-related problems to be expected. Another concern is the apparently simplistic approach to engineering design described in Section 4 of the E.I.S. The approach given may lead the reader to assume that construction and operation will be quite straight forward and simple rather than highly original and innovative.

Several items receive little or no attention, but should be discussed even if only briefly. Geophysical methods have improved dramatically in the past several years and now warrant serious consideration as surficial mapping tools. Both climate and terrain are highly variable parameters both spatially along the right-of-way and temporally during the operating life-time of the pipeline. Temporal effects are second order in comparison to the spatial variations but none the less may have a serious long term impact. Ground-water movement receives little attention although it will have a major role in the performance of a buried pipeline particularly in the chilled mode. Post-construction surveillance and monitoring of the pipeline and related facilities will be very important if an innovative technique such as burial in permafrost in a chilled operating mode is adopted. General plans for this phase need to be formulated.

Since E.P.B. has collected some additional permafrost and ground temperature information I have summarized our results and conclusions in relation to those equally sparse data included in the E.I.S. I realize that Foothills has major observational programmes currently underway so the sparseness of present data should not necessarily be seen as a further deficiency in the Company's investigations.

Lastly, I would like to see a scientific programme considered which would use portions of the pipeline as a reasonably accessible large open-air laboratory. Such studies would enhance our scientific understanding of northern processes and lead to improved northern development. The costs of such investigations should not accrue to Foothills, since they benefit the nation as a whole.

In the remainder of this critique I have attempted to amplify each of the foregoing comments.

Technical Comments

1. Presenting an assessment of the probable impact upon the northern environment of such a major innovative engineering undertaking as the Alaska Highway gas pipeline is a very difficult task. In this instance considerable environmental insight on some constructional and environmental aspects of the proposal could have been gleaned by reference to the performance of other structures previously constructed across permafrost terrains in the region; specifically the 25-year history of the Haines-Fairbanks pipeline right-of-way and the performance of Yukon roads such as the Alaska Highway where they cross sensitive terrain.

2. The E.I.S. omits any discussion of the advantages and disadvantages of the various design modes of the pipeline. Selection of the buried mode may well be the most practical but when such a controversial mode of operation as a buried chilled system is proposed, I believe that it is essential to explain the rejection of other operational modes. The operation of both warm and chilled pipelines is still an unknown quantity technically; pipelines across permafrost are still largely in the evaluation stage and so we must assume that problems causing an interruption of the gas throughput will arise. While the report does state on page 8-3 that few maintenance problems are anticipated along the buried pipe, I am not sure that U.S. natural gas transmission line data from non-permafrost areas is applicable to pipelines in permafrost.

In the Soviet Union where greater numbers of northern gas lines already exist as many as 8 to 12 ruptures per year averaging 50 to 70m in length are encountered on the very large diameter (56 inch) northern natural gas pipelines as reported by Sanders (1976).

The possibility of maintenance work being required on a pipe in the deep burial mode other than at times when the surface is completely frozen raises the spectre of local environmental damage outweighing any caused during winter construction. Since 8-3 also contains the statement that little or no storage of gas will be incorporated into the system south of permafrost areas, rapid repair of any ruptures in the northern sections will be necessary to ensure continuity of supply to customers. Protection of the environment could necessarily become of secondary concern in such circumstances. Elevation of the pipe over short stretches of sensitive terrain would utilise a better understood technology with presumably a greater reliability. Access to the pipe for maintenance is simpler particularly if gravel access roads are built along such sections of the right-of-way.

3. Very little discussion of the "philosophy" of chilled versus warm mode operation is included in the E.I.S. If indeed these are the modes to be used these alternatives need outlining in greater detail. In section 4.2.2.1 page 4-24 it is mentioned that the chilled mode will probably be employed between the Alaskan border and compressor station FY-1, the initial 46km. Fig. 6.2-1 however indicates very little if any systematic change in mean ground temperature at 3m depth over the first 150km with the exception of taliks under lakes and the flood plains of rivers. Buried warm-mode operation over 100km of permafrost terrain of mean surface temperature -2 to -4°C, and occasional high ice content, presents considerable problems which may be more serious than chilled-mode operation.

4. Section 4 of the E.I.S. illustrates, by several examples, the approach to engineering design adopted by the Company. This is an excellent way of illustrating how engineering design proceeds but I have some concern that it may give an overall impression of simplicity and confidence at this very early design stage, thus detracting from the innovative nature of the chilled buried mode and other concepts such as deep burial. The section does not stress sufficiently the very poor understanding that science

presently has of northern processes such as moisture migration and frost heave in frozen or partially frozen terrains and the consequent need for conservative design. "Geothermal analysis" is a useful preliminary tool but the mathematical equations included are only as good as our knowledge of the physical environment and field observations are necessary to confirm their applicability. The geothermal model used in the compressor station design described in 4.2.1.2 (i) is a conductive unidirectional model. It assumes that the borehole lithology shown in Figure 4.2-2(a) and (b) is semi-infinite in all directions, that the energy transfer between air and ground can be represented by simple standard meterological observations, is static from year to year, and that heat transfer in the ground is by conduction only and solely in a vertical direction. Thermal properties are, I believe, not measured directly but are inferred from other measured engineering parameters. Any active moisture movement will transfer heat much more efficiently and could change estimated effects in the original ground surface by several orders of magnitude. Similarly section 4.2.2. that describes the frost-heave of various chilled pipe configurations makes many simplifying assumptions regarding the availability of moisture and the upper bounds of ice content. If this simple model completely described the process, little of the tens of metres of massive ice observed in the northern subsurface would form. It should be noted that the curves shown in Fig. 4.2-24 showing frost depth growth below the pipe against time become essentially linear after 10 to 15 years. The rate of frost penetration and segregated ice formation is very complex and depends on the supply of moisture, the hydraulic conductivity of the unfrozen, partially frozen and freezing soils, pore pressure and temperature gradients amongst other factors. For such a highly innovative engineering project in terrains where we do not fully understand the geotechnical conditions, we must accept that the calculations are illustrative only and that final design has to be based on the results obtained from carefully monitored test facilities. The geothermal and frost-heave models must be tested against real data. Perhaps their greatest value is to test them against field results to learn where they are deficient. Numerical analysis is much easier and cheaper to do than carefully conceived field experiments, as might be well illustrated by comparing Figs. 4.2.3, the computed results, and the observed data shown in Fig. 4.2.7. As I am sure the company would agree numerical analysis requires both good input data and a good comprehension of the basic physics of the problem. The innovative, almost experimental, nature of the some northern sections of pipeline should be stressed from the start. Equally well we must not assume that the pipeline construction will constitute an environmental disaster. The Trans-Alaska pipeline was similarly innovative and underwent several changes in design before construction began.

5. Geophysical methods, as surficial mapping tools, appear to have largely been ignored in the E.I.S. despite significant improvements in the past few years, especially in radar techniques. I look forward to seeing the Hardy and Associates report on geophysical methods described as item (4) on page 6-15 and presumably item (4) on page 3-9. One of the inherent assumptions made for the simple calculations given in section 4.2.1.2 is that geological strata are horizontal and continuous. Unconsolidated

sediments and ice content in reality may vary considerably over very short distances. Doubts as to the value of drilling alone for detailed design have already been raised at workshops of the U.S. Permafrost Committee as a result of the Alyeska experience (Judge, 1978). The Alyeska people have stressed the need to apply geophysical methods, with occasional drilling for ground truth, to determine the spatial variability of lithology and ice contents.

6. Climate and terrain are not static in time as is illustrated by the brief summaries of the geological history and of geomorphic processes in 6.2.4 of the E.I.S. However the assumption seems to have been made that over shorter periods of time such as a few decades unchanging conditions can be assumed. A growing body of evidence suggests that this assumption is invalid. Section 6.1 of the E.I.S. presents an analysis of climatic data for a period of 29 years but presents only means and extreme values. Presumably the lifetime of the pipeline is greater than 20 years, e.g. Fig. 4-2-24 extends to 30 years, a period over which the assumption of a static mean climate is probably invalid. Long-term changes in climate are usually paralleled by changes in ground temperature inducing consequent geomorphic effects in permafrost terrains as described by Judge (1975). Both Judge (1973) and Mackay (1975) have described thermal and geomorphic evidence for general ground temperature changes of as much as 2°C in areas of the Mackenzie Valley and Delta over the past century. The long term warming during this period has reactivated thermokarst lakes in discontinuous permafrost zones of the central and southern Mackenzie Valley and the onset of a cooling trend in the past decade has reactivated

ice-wedges on the Arctic coast. A quick glance at the long term air temperature records for Fairbanks, Alaska, reveals a warmer period by about 1°C during 1925-45 which has been superceded by a cooling trend since 1966. Tree-ring growth curves from central Alaska indicate a warmer period since 1930 (Hauger and Brown, 1978). A study of ice-wedge fabrics in the Fairbanks area has suggested that wedges are currently growing locally (Black, 1978). Geomorphic processes are highly dynamic even without major changes in climate and can further add to the complexities of permafrost behaviour. Such concerns lead to a series of questions about the long-term natural geomorphic performance of the landscape and how it may impact on any long-lived structures. As examples;

a) Have the active thermokarst lakes described on page 6-75 been reactivated in the past century and what are the present rates of enlargement?

b) Are the ice-wedges north of the White River described on page 6-75 active? If so, what are the rates of growth, and if not what change in conditions such as ground temperature would be necessary to reinitiate their growth?

c) Are observed permafrost thermal profiles in the Yukon degradational in character? Could this explain fig. 4.2.7? If so the temperature: depth profiles and the thaw-subsidence calculation made using the "geothermal analysis" programme are invalid as they underestimate thaw-subsidence effects. Similarly, degrading permafrost contains zones of excess free-moisture and underconsolidated sediments, all of which can pose problems in general pipe design and perhaps cause underestimates in the amount and rate of frost heave in a chilled mode of operation.

d) Is there evidence of extensive recent degradation of ice in high ice content soils at the warm margins of the discontinuous permafrost? Natural soil conditions may be especially unstable in this area.

e) If a cooling trend has recently set in, active ice segragation may be occurring naturally in the near-surface, e.g. at the base of active layer in areas of frost susceptible soils.

f) Following from page 6-74, are there oversteepened slopes frozen in place by permafrost? Are they presently stable? Zones of high water content resulting from the melting of ground ice may produce zones of weakness and block sliding. Does evidence exist for increased slope activity in the past century?

g) The unique thermal properties of the White River volcanic ash as an insulator are mentioned on p. 6-74. If it is indeed preserving relic permafrost what will be the overall impact and thaw-subsidence resulting from a ditch through it in which a pipeline is buried and operated in the warm mode?

I believe that these very few examples will serve to illustrate my concerns for the pipeline although many others could be cited. Perhaps the possible readvance of the Lowell or Kaskawulsh Glaciers in response to a cooling climate, as appears to have happened during the Little Ice Age of the seventeenth century, and the resulting potential impact both on the pipeline and the communities such as Haines Junction should not go unmentioned.

Since climatic records from the Yukon span a period of only 30 years, long term trend analysis is difficult. These trends usually are translated into ground temperature changes and consequently produce distinctive temperature: depth profiles. Beck and Judge (1969) and Gold and Lachenbruch (1973) have shown how careful analysis of the upper 60 to 90m of subsurface temperature profiles can reveal changes in the past century and current trends.

7. Many of the large rivers in the Yukon are glacier-fed and show every evidence of being youthful and of high energy. Such rivers may need some caution in predicting their extreme behaviour for the next 30 years. Section 6.3 of the E.I.S. contains very little information on long-term surface hydrological activity. To extend the data-base in time, historical records might be examined. Recent retreat or otherwise of snow-lines and glaciers with corresponding vegetational changes might further add to a long-term prediction of flows in the Slims, Donjek and White Rivers.

8. The growth of a frost-bulb around a chilled buried pipeline will be dependent on ground-water conditions as described in section 4 of this report. Potentially the most serious effects will result at river crossings from sub-river ground-water flow. If chilled-mode operation is only contemplated for the first 50 km then sub-river ground-water flow conditions may be important parameters for 4 small creeks (Snag, Beaver, Enger and Dry). If Fig. 4.2-17, the section across Dry Creek, is representative of these creeks, then the permafrost configuration indicates the possibility of substantial ground-water movement. Blockage of the flow by the growth of a large frost-bulb in a water-rich environment may induce high pore-pressures on the upstream side and the possible formation of winter iceings creating high stresses on the pipe. Should further chilled sections be contemplated additional river-crossings will need investigation.

Similarly the growth of a frost-bulb in the terrestrial environment will be partially governed by the supply of moisture, and yet section 6.3 of the E.I.S. makes little mention of ground-water activity even in its simplest form of, for example, a list of springs. The Takhini hot springs on p. 6-80 and the withdrawal of ground-water from beneath the permafrost at Beaver Creek on page 4-19 are the only direct references.
Supra-permafrost water moving in the active layer or diverted along the highly permeable gravel filled pipeline ditch as described in section 9.1.1.1 will need very careful investigation. Intra-permafrost water such as the unfrozen porewater in frozen sediment controls the hydraulic conductivity and thus partially the rate of growth of a frost-bulb around

the chilled pipe. Some recent results have suggested that permafrost in some areas may contain lower unfrozen water contents and thus perhaps lower hydraulic conductivities than indicated by laboratory observations on artificial soils (Judge 1978). Areas of degrading permafrost may contain intra-permafrost zones of high pore pressures at above hydrostatic pressure which could contribute to increased frost-bulb development in a chilled mode.

Indications of the mobility of water within the permafrost can be obtained by careful isotope analysis of the water and ice in cores recovered from the region. Recent increased or decreased thickness of the active layer or the presence of recent water seepage into the permafrost from the surface should be preserved in the ratios and variability of oxygen, hydrogen and carbon isotopes. Old stable permafrost appears to have very uniform isotopic distribution (Fritz and Michel, 1978).

9. In many instances the E.I.S. is deficient in information on permafrost and ground temperature distribution. Discussion of permafrost-related items of the E.I.S. could be enhanced by the presentation of additional information which I am sure will be forthcoming from the Company prior to any final project design. Although fiscal restraint has prevented extensive programmes in the Yukon EPB does have some data in addition to that reported by Foothills. This I have summarized below in the belief that it will assist in the preliminary discussions of design at this stage.

In section 6.2.2.1 on page 6-16 and on page 6-74 permafrost is reported to generally exceed 45m depth on the Klondike Plateau. Our observations at Clinton Creek, north of Beaver Creek reveal 125 m of permafrost with a mean annual ground temperature of -4°C. None of the temperature measurements that we have made in the Whitehorse area have encountered permafrost and mean ground temperatures have ranged from 0.7 to 3.0°C. As stated on p. 6-75 its presence is probably very isolated e.g. Whitehorse Copper have reported occurrences high on north-facing slopes. In common with the statement on p. 6-77 we observe no permafrost on the Nisutlin Plateau in the vicinity of Atlin. Mean ground temperatures in four drillholes between 1400 and 1550m a.s.l. ranged from 0.5 to 3°C. Tallman (1973) inferred 15 to 20m of permafrost in a peat bog at 1000m from electrical resistivity measurements in the same area indicating some sporadic permafrost. Observations in drillholes to the east at Faro have revealed sporadic permafrost centred largely in areas of thick overburden. As yet too few observations have been made to determine if it is relic in nature. Of the shallow ground temperatures measured in 15 holes along the Alcan pipeline right-of-way of depth ranging from 3 to 9m during November 1978, all were negative north of Kluane Lake and none were to the south; the lowest values were -2.6°C and the highest 2.0°C (Burgess and Allen, 1979).

10. Section 6.2.6 on ground temperature measurements indicates that available information along the right-of-way is sparse although extensive observations are presently underway. Some general indication of ground temperatures may be derived for initial planning by comparison of air and

ground temperatures in other areas of Canada. It is interesting to observe in section 6.2.6.1 that 10 ground temperatures observations in the Western Yukon Plateau and Klondike Plateau range from 0.5 to -3.6°C in response to average mean air temperatures of -5.5 to -6.0°C. In comparison the mean air temperature at Yellowknife is -5.4 to -6.2°C and ground temperatures range from -1.8 to 1.5°C and at Norman Wells in response to a mean air temperature of -6.2°C mean ground temperatures range from -1.1 to -3.8°C. On average for 38 sites across Canada the mean ground temperature is 3.3 ± 1.5°C higher than the mean air temperature. Winter snow cover is a very important factor in determining this difference (Judge, 1973). The results of Foothills present ground temperature studies will be a valuable addition to the current body of data.

11. In view of the originality of many concepts to be used in the technical design of the pipeline, careful post-construction surveillance and extensive electronic monitoring will be necessary. Neither Sections 9 nor 2.4.4 give adequate consideration to this aspect.

12. Although not of direct impact to the construction of the Alaska Highway gas pipeline or this E.I.S. some thought should be given at this stage to the formulation of a post-construction scientific programme utilising sections of the pipeline and its right-of-way. The presence of the pipeline will present unique opportunities as a reasonably accessible open-air laboratory. This concept was earlier discussed in connection with the Trans-Alaska pipeline and led to a detailed report on the research opportunities presented by the pipeline (NAS, 1975).

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